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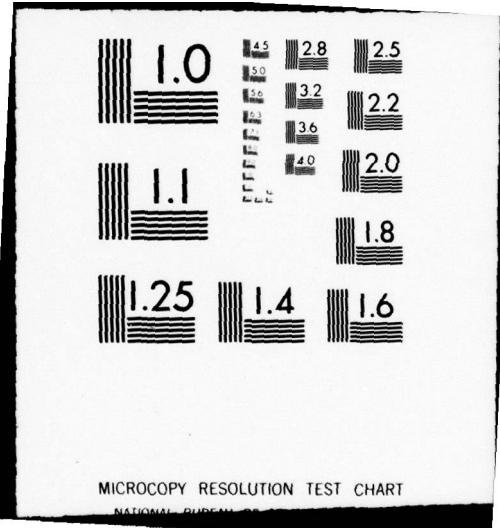
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SIDE-CHANNEL SPILLWAY AND OUTLET
WORKS FOR SAN ANTONIO DAM

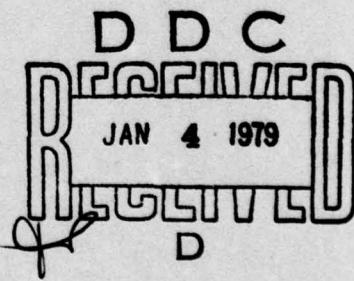
Hydraulic Model Investigation



Report No. 2-106

October 1978

U. S. Army Engineer District, Los Angeles
CORPS OF ENGINEERS
Los Angeles, California



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20. ABSTRACT (Continued).

→ Although the spillway crest functioned satisfactorily as originally designed, excessive ride-up and turbulence in the side channel during the maximum design flow of 54,000 cfs indicated the need for improved performance of the channel. The addition of baffle blocks on the side-channel invert provided adequate control of the flow and reduced the excessive ride-up occurring in the channel. The flow in the spillway chute was more stable and less turbulent. A flip bucket with a radius of 75 ft and a terminal slope of 20 degrees above the horizontal is provided at the end of the chute. The bucket proved to be satisfactory and produced a favorable hydraulic action. At a spillway flow of 54,000 cfs, the bucket diffused the spillway jet quite well over the surface of the water and resulted in a lesser degree of erosion well removed from the end of the structure. Design wall heights were determined from water-surface profiles measured in the model.

Tests of the intake structure and outlet circular conduit disclosed that the flow conditions were acceptable. The slide gates were calibrated, and the outlet conduit discharge capacity curve was determined. Open-channel flow on the rising stage existed up to a discharge of 9,000 cfs; at discharges greater than 9,000 cfs, and with a falling stage down to 8,000 cfs, the conduit flowed full.

The diversion structure at the downstream end of the conduit was designed to accommodate an ultimate flow of 1,000 cfs through the diversion chamber and to divert 700 cfs to the left part of the spreading grounds which is in San Bernardino County and 300 cfs to the right part which is in Los Angeles County. Flow conditions were investigated for discharges from 1,000 cfs to 11,000 cfs flowing in the conduit, and the gate openings were varied for certain discharges in order to observe flow characteristics in the diversion chamber. Results of the investigations revealed that for a discharge of 1,000 cfs, the performance of the diversion structure was satisfactory. The measured discharge to each part of the spreading grounds agreed with the design assumptions. As the flow in the outlet conduit was increased, however, the disturbance at the entrance to the chamber became more pronounced. For higher discharges, the impact flow on the downstream edge of the slot caused the water to spray over a large area. A spray shield was proposed to prevent water from splashing over the channel walls.

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FOREWORD

The hydraulic studies reported herein were conducted in the Hydraulic Laboratory of the U. S. Army Engineer District, Los Angeles, during the period 1954-1956. Preparation and publication of the report were authorized by the Office, Chief of Engineers, in a letter dated 21 August 1969 to the Director, U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The basic model data used in the preparation of this report are available from the Permanent Data Files of WES. This report is submitted, in compliance with requirements of ER 1110-1-8100, to present the data and results of model studies for the spillway and outlet works of San Antonio Dam.

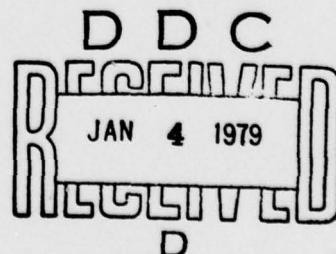
This report was prepared by Mr. Dave A. Barela, Hydraulics Section, Los Angeles District, under the supervision of Mr. Alfonso Robles, Jr., Chief of the Hydrology and Hydraulics Branch.

Detailed results of two model studies on spreading ground diversion structures are inclosed as Appendix A to this report. The diversion structures are part of the San Antonio and Chino Creeks improvement. COL John V. Foley, CE, was District Engineer during publication of the report.

The report was reviewed and published by WES. COL John L. Cannon was Director of WES during publication of the report; Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square miles (U. S. statute)	2.589988	square kilometres
feet per second	0.3048	metres per second
cubic feet per second	0.02831685	cubic metres per second
degrees (angle)	0.01745329	radians

SUMMARY

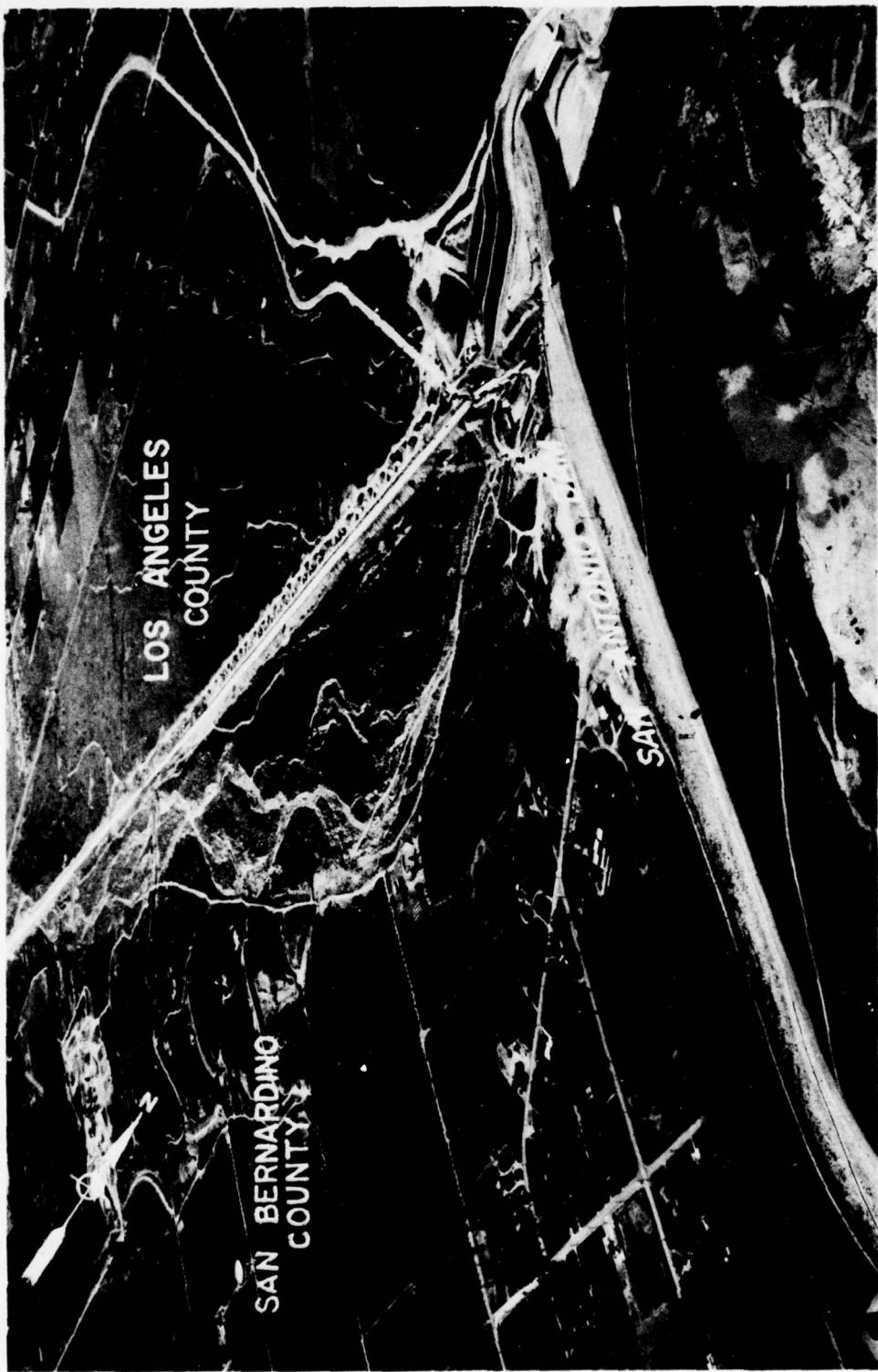
Model studies of the proposed uncontrolled side-channel spillway and outlet works for San Antonio Dam were conducted to develop, by means of 1:36- and 1:48-scale models of the spillway and a 1:20-scale model of the outlet works, satisfactory and economical designs for these elements. Particular attention was given to flow characteristics in the side channel, spillway chute, and flip bucket for the side-channel spillway and to performance of the intake structure, outlet conduit, and diversion structure for the outlet works.

Although the spillway crest functioned satisfactorily as originally designed, excessive ride-up and turbulence in the side channel during the maximum design flow of 54,000 cfs indicated the need for improved performance of the channel. The addition of baffle blocks on the side-channel invert provided adequate control of the flow and reduced the excessive ride-up occurring in the channel. The flow in the spillway chute was more stable and less turbulent. A flip bucket with a radius of 75 ft and a terminal slope of 20 degrees above the horizontal is provided at the end of the chute. The bucket proved to be satisfactory and produced a favorable hydraulic action. At a spillway flow of 54,000 cfs, the bucket diffused the spillway jet quite well over the surface of the water and resulted in a lesser degree of erosion well removed from the end of the structure. Design wall heights were determined from water-surface profiles measured in the model.

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The diversion structure at the downstream end of the conduit was designed to accommodate an ultimate flow of 1,000 cfs through the diversion chamber and to divert 700 cfs to the left part of the spreading grounds which is in San Bernardino County and 300 cfs to the right part

which is in Los Angeles County. Flow conditions were investigated for discharges from 1,000 cfs to 11,000 cfs flowing in the conduit, and the gate openings were varied for certain discharges in order to observe flow characteristics in the diversion chamber. Results of the investigations revealed that for a discharge of 1,000 cfs, the performance of the diversion structure was satisfactory. The measured discharge to each part of the spreading grounds agreed with the design assumptions. As the flow in the outlet conduit was increased, however, the disturbance at the entrance to the chamber became more pronounced. For higher discharges, the impact flow on the downstream edge of the slot caused the water to spray over a large area. A spray shield was proposed to prevent water from splashing over the channel walls.



The prototype

SIDE-CHANNEL SPILLWAY AND OUTLET WORKS

FOR SAN ANTONIO DAM

Hydraulic Model Investigation

PART I: INTRODUCTION

1. The model studies described herein were made to study flow conditions in the side-channel spillway and superelevated spillway chute, outlet works, and water-conservation diversion structure of San Antonio Dam and to develop means of correcting any unsafe and undesirable conditions found to exist in the proposed designs.

The Prototype

2. San Antonio Dam is located at the mouth of San Antonio Canyon in the San Gabriel Mountains about 30 miles* east of Los Angeles, California (Plate 1). The rolled earth-fill embankment, with crest at el 2,260 ft msl,** is 160 ft above streambed and 3,850 ft long. The dam also has a side-channel spillway, spillway chute, and outlet works that include an intake structure, a transition structure, an outlet conduit, and a diversion structure.

3. The spillway is a concrete, ogee-type structure located on the right abutment of the dam, with crest at el 2,238 and a length of 200 ft. Design shape of the weir downstream of the crest conformed to the equation $X^{1.85} = 2H_d^{0.85}Y$. A head of 13.0 ft was used as the design head (H_d) although the maximum head expected was 17.0 ft. The ogee curve terminates at a point where the tangent has a slope of 1V on 0.80H. The tangent is extended to the bottom of the side channel to form the lower part of the downstream face. Upstream of the crest, the weir is shaped by a compound circular curve of 2.60- and 6.50-ft radii.

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page v.

** Elevations (el) cited herein are in feet referred to mean sea level.

The upstream face is vertical with the approach apron 10 ft below the crest. The spillway is designed to pass 54,000 cfs under a maximum head of 17.0 ft.

4. The side channel, formed by the ogee and a vertical wall located 70 ft at the upstream end and 85 ft at the downstream end from the ogee face at the invert, is on a longitudinal slope of 0.050. The sidewall and upstream end wall are joined by a 50-ft-radius curve. The spillway chute begins at the downstream end of the ogee and is 809 ft long. The alignment of the chute, which varies in width from 80 ft at the upstream end to 50 ft at the downstream end, has a curve with a radius of 474 ft. The invert of the spillway chute throughout the curve is superelevated in varying amounts up to a maximum of 14.8 ft. A flip bucket is provided at the end of the chute.

5. The outlet works, located about 600 ft east of the spillway through the embankment, consist of an intake structure composed of three 5-ft-8-in. by 10-ft gated passages, an access gallery to the control house, a transition structure 86.44 ft long, and an outlet conduit 14.5 ft in diameter and 508 ft long. The intake roof was shaped to the elliptical curve defined by the equation $X^2/D^2 + Y^2/(2/3D)^2 = 1$ where D is the conduit height. The equation for the side horizontal curve of the bell mouth recommended by the U. S. Army Engineer Waterways Experiment Station is $X^2/D^2 + Y^2/(D/3)^2 = 1$ where D is the width of intake conduit. However, for San Antonio Dam, only the piers separating the three intake conduits would be shaped to form a bell mouth. An ellipse having the equation $Y^2 = (64 - X^2)/9$ was derived for shaping the upstream end of the piers. This equation gives a longer curve than $X^2/D^2 + Y^2/(D/3)^2 = 1$ so that no severe negative pressure should develop. Details of the design of the intake curves are given in Plate 2. Three air vents were provided, one for each gate. A transition from the gates is required to convey the flow from the three 5-ft-8-in. by 10-ft conduits to a single circular 14.5-ft-diam conduit. Reverse circular curves were used in the sidewalls to reduce the overall width from 27 ft 8 in. at the gates to 14.5 ft in diameter at the circular conduit. A straight-line roof transition was used to change the height from 10 ft

at the gate section to 14.5 ft at the circular conduit. The transition from rectangular to circular was accomplished by the use of fillets. The outlet conduit has a capacity of 11,000 cfs with water surface at spillway crest, but the outflow will be controlled to a maximum of 8,000 cfs. The diversion structure, which is located at and connected to the end of the conduit, intercepts and diverts all flow up to 1,000 cfs to the water conservation spreading grounds along both sides of the channel. The diversion structure consists of a chamber that is 22 ft wide and 10 ft deep underneath the open-channel invert. The flow enters the chamber through an 11-ft slot across the invert that is 14.5 ft wide. Vertical slide gates located in the sidewalls of the diversion chamber are provided to control the flows to the spreading grounds.

Purpose of Study

6. Model tests were made to study the overall hydraulic performance of the spillway and outlet works prior to construction. Investigations were made to determine (a) the shape of the side-channel spillway and its approach, (b) the capacity of the spillway chute, (c) the design of the intake structure and outlet conduit, and (d) the effectiveness of the diversion structure.

PART II: THE MODELS

Description

7. Three models were used in the investigations of the hydraulic performance of the spillway and outlet works for San Antonio Dam. A 1:36-scale model reproduced the uncontrolled side-channel spillway and a portion of the spillway chute. A 1:48-scale model reproduced the side-channel spillway, spillway chute, flip bucket, and dispersal area. A 1:20-scale model of the outlet works included a portion of San Antonio Creek channel, the gated intake structure, transition structure, and circular outlet conduit.

8. Materials used in the construction of the models were wood, lucite, sand, cement, and gravel. The side-channel spillway, spillway chute, and flip bucket were constructed of wood in the form of timber and plywood to simulate the reinforced concrete structure of the prototype. The spillway approach area was molded in cement mortar and sand. The dispersal area downstream of the flip bucket was molded in sand and gravel to simulate the streambed and stone protection. Models of the outlet works and the diversion structure were constructed of lucite. The reservoir area was represented by a forebay properly baffled and of sufficient size to ensure representative approach conditions to the intake structure. A piezometer opening, connected to a glass manometer by a flexible tube, was used to obtain measurements of pool elevations. Water was supplied to the models from a recirculating system and was measured by a venturi meter in the supply lines. After passing through the models, the water was returned to an underground sump by means of gravity lines.

Scale Relations

9. The accepted equations of hydraulic similitude based upon the Froudian relations were used to express mathematical relations of the dimensions and hydraulic quantities between model and prototype.

General relations for the transference of model data to prototype equivalents, or vice versa, are presented in the following tabulation where the subscript "r" represents model-to-prototype scale ratio:

<u>Dimension</u>	<u>Ratio</u>	<u>Scale Relations</u>		
		<u>Model No. 1</u>	<u>Model No. 2</u>	<u>Model No. 3</u>
Length	L_r	1:36	1:48	1:20
Area	$A_r = L_r^2$	1:1,296	1:2,304	1:400
Velocity	$V_r = L_r^{1/2}$	1:6.00	1:6.93	1:4.47
Discharge	$Q_r = L_r^{5/2}$	1:7,776	1:15,926	1:1,789
Roughness	$N_r = L_r^{1/6}$	1:1.82	1:1.91	1:1.65

10. Measurements of discharge and depth of flow can be transferred quantitatively from model to prototype equivalents by means of the above scale relations.

PART III: TESTS AND RESULTS

Spillway Crest and Side Channel

11. The first model was constructed to a scale ratio of 1:36 to simulate the spillway crest and the side-channel spillway (Photo 1). Details of the spillway crest are shown in Plate 3. No alterations were made to the spillway crest during the model studies. It was previously mentioned that the spillway crest was designed to pass 54,000 cfs under a head of 17.0 ft. Test results indicated that although flow distribution in the upstream approach and at the spillway was satisfactory, flow in the side channel needed improvement. Excessive ride-up occurred on the vertical outer wall, and the flow was very turbulent and unstable in the side channel. Further tests conducted with the addition of baffle blocks on the side-channel invert indicated a much improved flow condition. The ride-up was reduced by about 5 ft, and the flow in the side channel was more stable and less turbulent (Photo 2). Longitudinal water-surface profiles within the side channel for a discharge of 54,000 cfs are shown in Plate 4.

12. The spillway crest was calibrated for heads up to 17 ft. The spillway discharges versus reservoir elevations are shown in Table 1. Plate 5 shows the rating curves, one computed and the other determined from the model data. Computed head-discharge relations conformed very closely to values that were observed in the model. Also shown in Plate 5 is the discharge-coefficient curve, computed from the model data by the use of the formula

$$Q = CLH^{3/2}$$

where

Q = discharge, cfs

C = coefficient of discharge

L = length of spillway crest

H = head (difference in elevation between the pool and spillway crest)

The computed rating curve did not include the effect of submergence on the spillway crest.

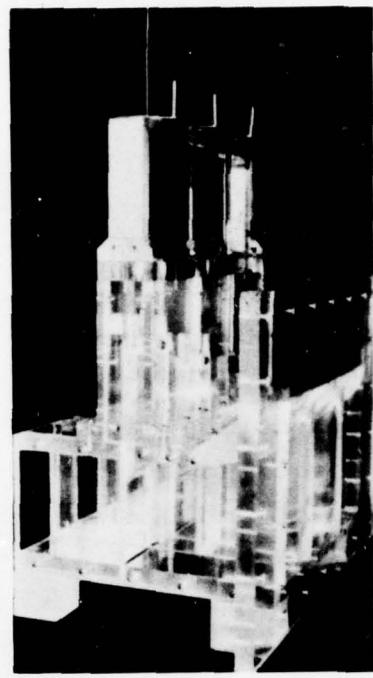
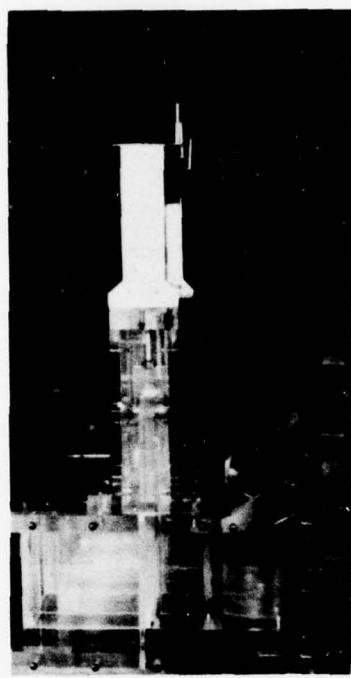
Spillway Chute

13. For this design, the model was entirely reconstructed as shown in Photo 3 and in Plates 6 and 7. The 1:48-scale model reproduced the complete spillway structure, including the spillway chute and flip bucket. The dispersal area also was incorporated in the model. The upper chute immediately downstream from the ogee began at sta 9+41 and extended on a constant width of 80 ft to sta 10+20.49. This reach had a slope of 0.003 and an adverse slope of 0.0389. The lower chute, which tapered to a width of 50 ft, had a slope at the center line of 0.380 and a slope of 0.040 upstream of the flip bucket.

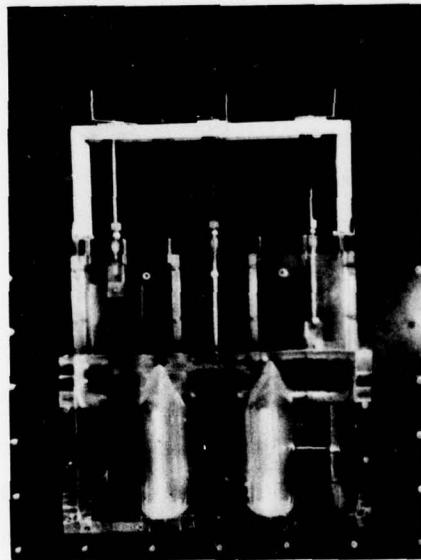
14. The model was tested for a discharge of 54,000 cfs, the results of which are shown in Photo 4. As previously mentioned, some improvement in the conditions of flow in the side channel was effected by the baffle blocks; however, the flow became more stable through as well as downstream from the curved transition. The water-surface profiles measured along both the right and left walls of the chute are shown in Plate 7. The profiles indicate that the wall heights provided adequate freeboard to confine the flow. The water-surface cross sections from sta 9+50 to sta 11+95.49 for a discharge of 54,000 cfs are presented in Plate 8.

Outlet Works

15. The model of the outlet works was constructed to a scale ratio of 1:20. Tests were divided into two general phases: (a) the intake structure and (b) the transition and circular conduit. Figures 1, 2, and 3 show the intake structure and component parts of the outlet works. Details also are shown in Plate 9. Flow from the intake structure is regulated by three vertical slide gates and discharged into three separate passages in the transition. Observations of flow



Side views

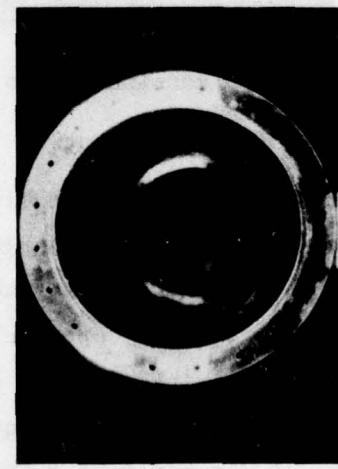
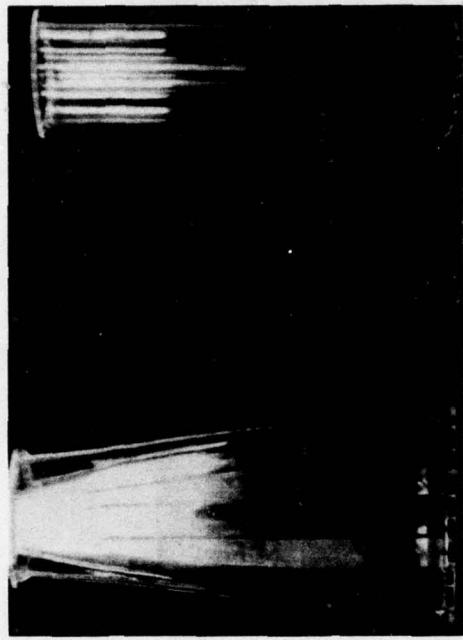


Downstream view

Figure 1. 1:20-scale intake structure



Upstream end view of transition



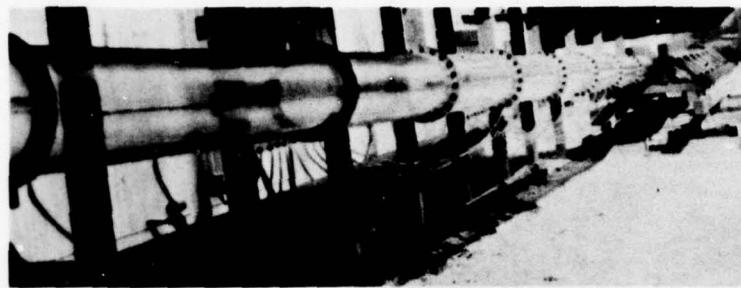
End view of circular conduit

a. Trifurcated transition (rectangular to octagonal)
b. Transition (octagonal to circular)
c. Circular conduit

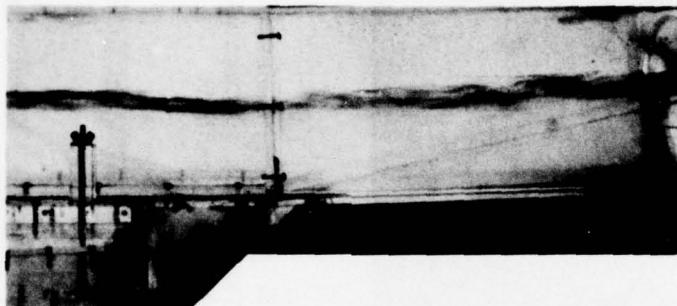


Composite transition

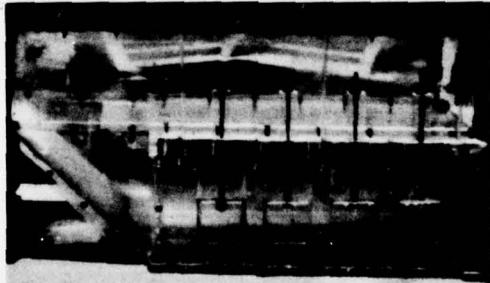
Figure 2. Components of outlet works



Outlet conduit



Flow through transition over diversion structure



Diversion structure

Figure 3. Outlet works

conditions in the gate passages and conduit were made for partial gate openings and a maximum controlled discharge of 8,000 cfs. At the beginning of the design flood (which was actually not tested in the model), all gates will be slightly open until the pool elevation reaches 2,238 ft (spillway crest). With the pool at el 2,238 ft and a rising stage, the outflow will be regulated to equal the inflow up to 8,000 cfs by opening the gates. A discharge of 8,000 cfs will then be maintained

with all gates opened 8.5 ft and pool el of 2,206.5 ft. Open-channel flow with surges occurred in the model outlet conduit. A calibration test was made on the three gates to determine the coefficients of discharge of various but equal gate openings. These data provided a comparison of the model operation with the suggested design curve (WES HDC chart 320-1*). Comparisons of the suggested and measured coefficient data are shown in Plate 10. Photo 5 shows the flow conditions for a discharge of 5,000 cfs and gate openings of 6.0 ft. Observations were also made of flow conditions in the transition and circular conduit for the following gate operations: (a) outer gates opened and center gate closed, (b) outer gates closed and center gate opened, and (c) all gates fully opened. Results of these observations are discussed in the following paragraph.

16. With low flows, conditions (a) and (b) were considered satisfactory. As the pool elevation rose, open-channel flow was observed in the transition and conduit. No attempt was made to obtain quantitative data during these tests; therefore model tests were accomplished by visual observation. With gates fully opened (condition (c)), observations of flow over the full range of discharges showed that the performance of the transition and conduit was satisfactory. At pool elevations below spillway crest (el 2,238), small vortices were observed in the vicinity of the intake; however, tests indicated that they had no measurable effect on the flow through the conduit. With a rising stage, surges occurred in the conduit between 3,000 and 9,000 cfs. At discharges greater than 9,000 cfs, the transition and entire conduit flowed full. With a falling stage, surges were not observed until the discharge was at 8,000 cfs, at which time the conduit flowed alternately full and partially full. These surges occurred until the discharge reached 3,000 cfs. At discharges below 3,000 cfs, the flow line was smooth and surges were eliminated. Discharge rating curves (experimental and a composite of computed curves) for full gate openings are

* U. S. Army Engineers, "Hydraulic Design Criteria," prepared for Office, Chief of Engineers, by U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., issued serially since 1952.

shown in Plate 11. The test revealed that within the pressure flow area the discharge capacity in the model was greater than the computed discharge capacity.

17. A supplement investigation at this point involved and attempt to prevent the surges in the conduit. The conduit was examined for performance under various gate operations. Results of these tests were not conclusive; however, the tests did indicate that the gates should be operated so as to provide symmetry of flow, thus improving flow conditions in the conduits. With the center gate opened 8.5 ft and the outlet gates opened 7.0 ft, the flow proved most satisfactory. There was no indication of surges in the conduit. Lowering of the center gate to an 8.0-ft opening indicated that surging would result; therefore it was concluded that the center gate should be kept opened 1.5 ft more than the outer gates. Below this differential, surges would develop.

Diversion Structure

18. Finally, attention was turned to the diversion structure proper. The model was constructed and tested at various locations along the outlet channel. Although provision was made in the model for the construction of the outlet channel at the downstream end of the diversion structure, this feature was used but not tested because the relatively small flows used in testing the diversion structure did not have any effect on the hydraulic performance of the outlet channel design; therefore testing was limited to the diversion structure. The final location recommended for the diversion structure was at the downstream end of the circular conduit. A transition, from a semicircular invert to a rectangular section, joins the conduit to the diversion structure. Details of the diversion structure and portion of the outlet channel are shown in Plate 12. The diversion structure was designed to carry a flow discharge of 1,000 cfs. The diversion flow was regulated by six vertical gates, two gates in the right wall and four gates in the left wall, and discharged into separate spreading grounds located on each side of the outlet channel.

19. The hydraulic characteristics of the structure were observed for various discharges and gate openings, either on one or both sides of the diversion chamber. The discharge to each spreading ground was measured volumetrically. With all gates open and a discharge of 1,000 cfs, the slotted invert into the diversion chamber accommodated all the flow without any interference. Results of the tests indicated that the structure satisfactorily diverted the desired amount of water to the spreading grounds. A discharge of 300 cfs was measured through the right side (two gates) and 700 cfs through the left side (four gates). The model was then tested for incremental discharges up to the maximum capacity of 11,000 cfs to determine if splashing would occur on the downstream leading edge of the slot. Under high heads, the pileup of water at the entrance to the diversion chamber created a great amount of spray. With all the gates closed, splashing occurred during certain ranges of discharges; however, the flow over the slot was more satisfactory than when the gates were opened. A splash cover was installed over the slot, which minimized the objectionable spray.

PART IV: CONCLUSIONS

20. The model investigations of the spillway crest, side channel, and outlet works for San Antonio Dam revealed the overall design of the structures to be adequate. Hydraulic performance of the spillway and spillway channel was satisfactory. The capacity of the spillway crest determined in the model tests was in close agreement with the computed capacity. The design discharge of 54,000 cfs passed over the spillway under a head of 17.0 ft, whereas the computed head for the same discharge was 16.5 ft. At the maximum head, the model data indicated a coefficient of 3.88. Model tests also indicated that the baffle blocks on the side-channel invert were needed to aid in reducing the turbulence in the channel and reduce the ride-up on the vertical wall opposite the ogee. The flip bucket, which had a radius of 75 ft and terminated at a slope of 20 degrees above the horizontal, was deemed adequate.

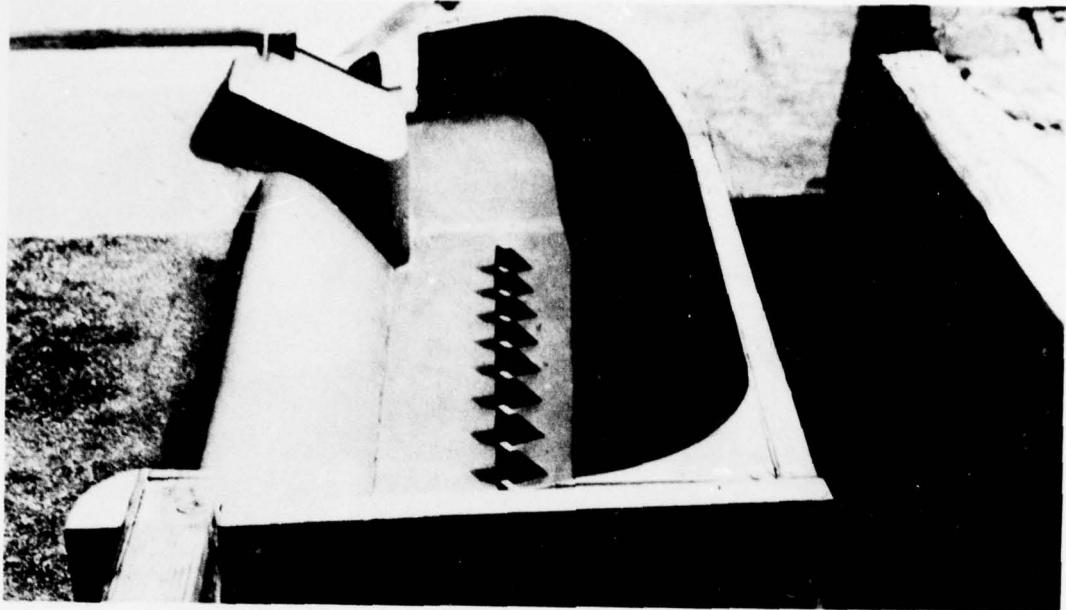
21. A summary of test results conducted on the outlet works is as follows:

- a. Intake structure. The structure operated satisfactorily for all rates of discharge. The curved piers and throat section guided flow to the gates with complete absence of turbulence.
- b. Gate operation. Gates should be operated so as to provide symmetry of flow, thus improving flow conditions in the conduit.
- c. Transition. The performance of the transition to convey the flow from the three separate passages to the single circular conduit was satisfactory. The flow line was generally smooth for all discharges.
- d. Conduit. Flow conditions in the conduit, resulting from all combinations of full gate openings, were satisfactory. With all three gates fully open, the head-discharge relation for low stages was comparable with the computed relation.
- e. Diversion structure. With all gates open and 1,000 cfs flowing in the conduit, the discharge into each part of the spreading grounds agreed with design assumptions; and only minor disturbances occurred at the gate opening and through the separate conduits. However, when the discharge was greatly increased in the outlet conduit, considerable disturbance occurred at the entrance of the

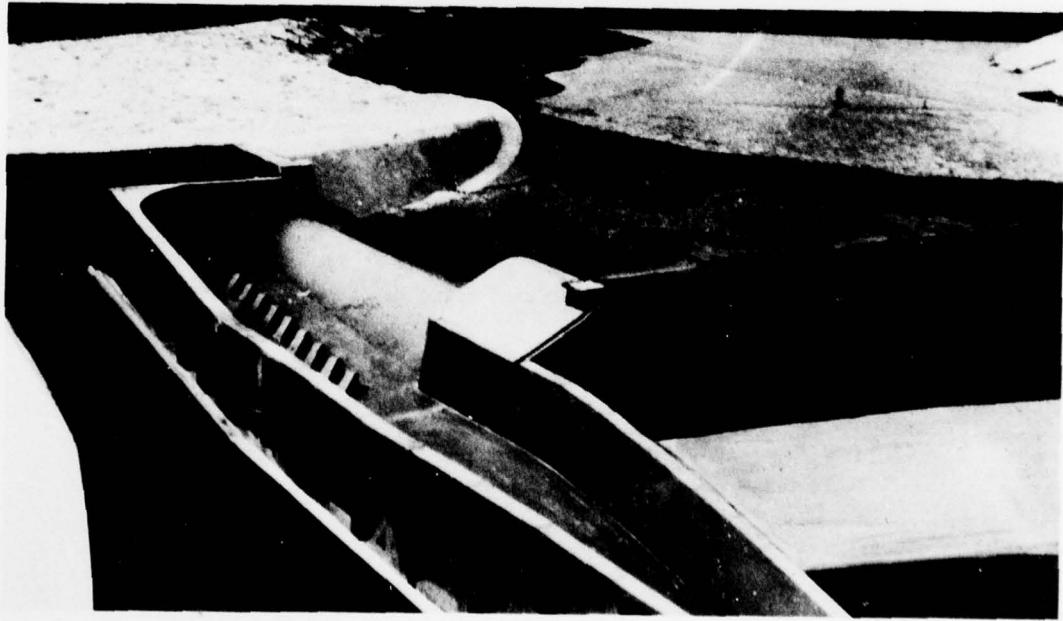
diversion chamber as evidenced by the splash; but the structure functioned satisfactorily with discharges up to 11,000 cfs without endangering the structure. In general, this diversion structure functioned as anticipated and resulted in satisfactory flow conditions for all discharges.

Table 1
Spillway Discharge Tabulation

Reservoir Elevation	Discharge, cfs							Average Difference
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	
2238	0	50	100	150	200	250	300	400
39	500	610	720	830	940	1,050	1,160	1,270
2240	1,600	1,740	1,880	2,030	2,170	2,310	2,450	2,590
41	3,020	3,210	3,400	3,590	3,780	3,970	4,160	4,350
42	4,920	5,150	5,400	5,630	5,870	6,110	6,350	6,590
43	7,300	7,560	7,810	8,060	8,320	8,580	8,830	9,080
44	9,850	10,140	10,440	10,740	11,030	11,320	11,620	11,920
2245	12,800	13,120	13,430	13,740	14,060	14,380	14,690	15,000
46	15,950	16,300	16,640	16,980	17,330	17,680	18,020	18,360
47	19,400	19,760	20,130	20,500	20,860	21,220	21,590	21,960
48	23,050	23,440	23,840	24,240	24,630	25,020	25,420	25,820
49	27,000	27,420	27,830	28,240	28,660	29,080	29,490	29,900
2250	31,150	31,600	32,050	32,500	32,950	33,400	33,850	34,300
51	35,650	36,100	36,560	37,020	37,470	37,920	38,380	38,840
52	40,200	40,660	41,130	41,600	42,060	42,520	42,990	43,460
53	44,850	45,320	45,800	46,280	46,750	47,220	47,700	48,180
54	49,600	50,080	50,570	51,060	51,540	52,020	52,510	53,000
2255	54,450	54,880	55,320	55,760	56,190	56,620	57,060	57,500
56	58,800	59,170	59,540	59,910	60,280	60,650	61,020	61,390
57	62,500	62,850	63,200	63,550	63,900	64,250	64,600	64,950
58	66,000	66,340	66,680	67,020	67,360	67,700	68,040	68,380
59	69,400	69,720	70,040	70,360	70,680	71,000	71,320	71,640
2260	72,600							

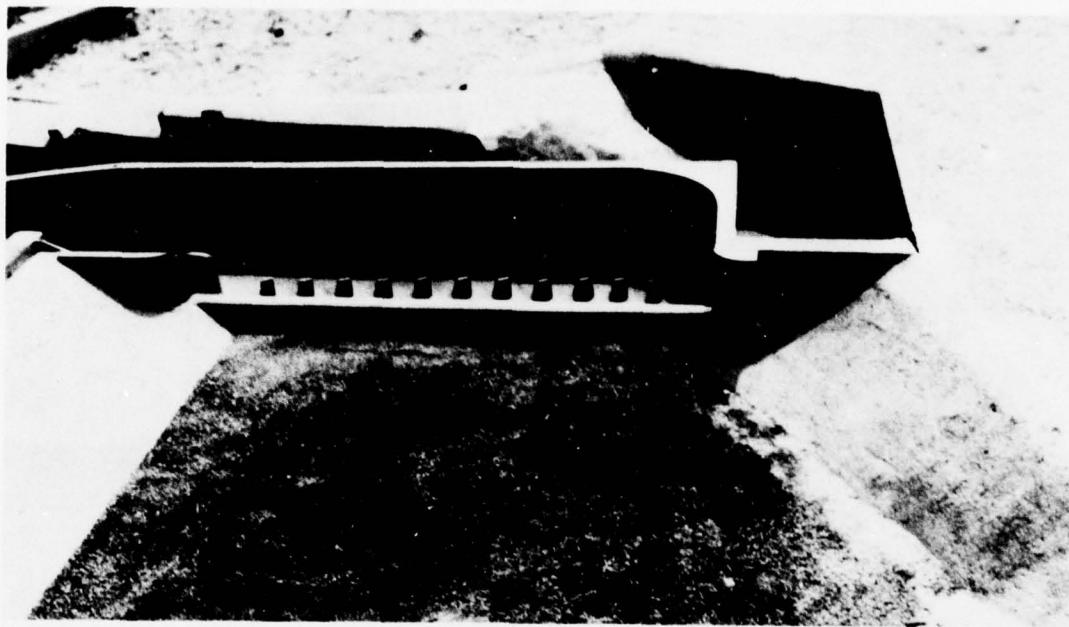


a. Downstream view of spillway channel



b. Upstream view

Photo 1. Final design, 1:36-scale model (sheet 1 of 2)



c. Approach to spillway crest, looking downstream

Photo 1 (sheet 2 of 2)

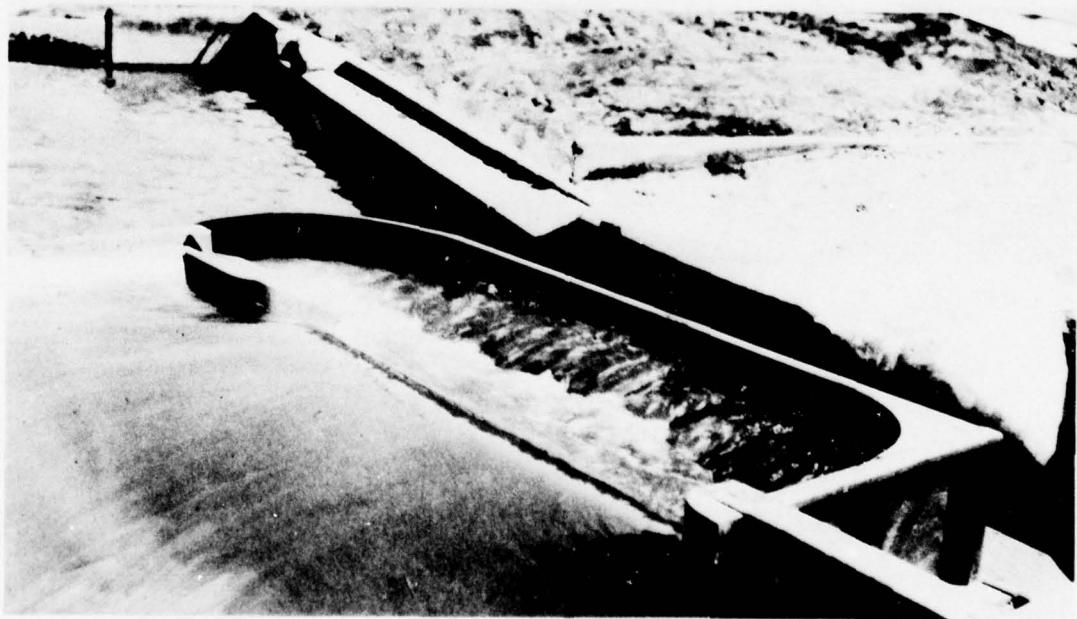
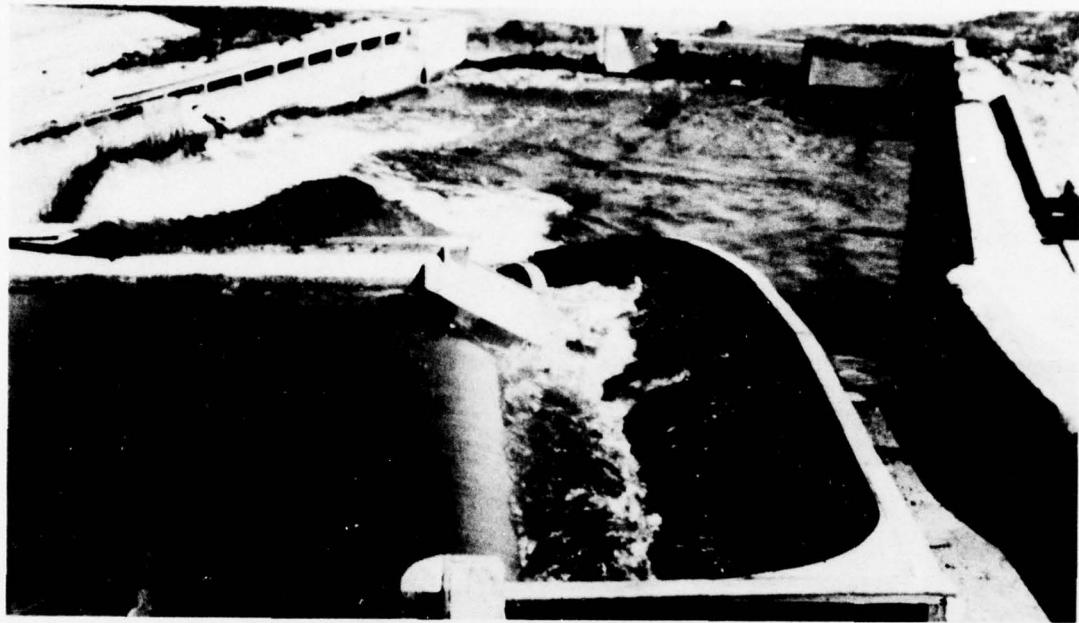


Photo 2. Final design flow conditions, 1:36-scale model,
discharge 54,000 cfs, downstream views

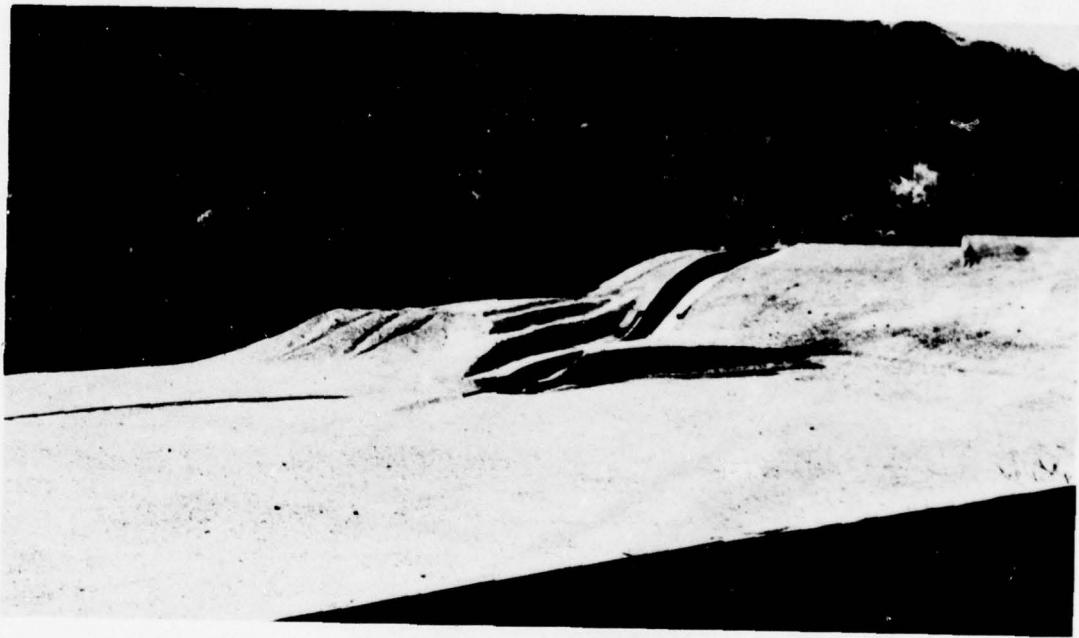
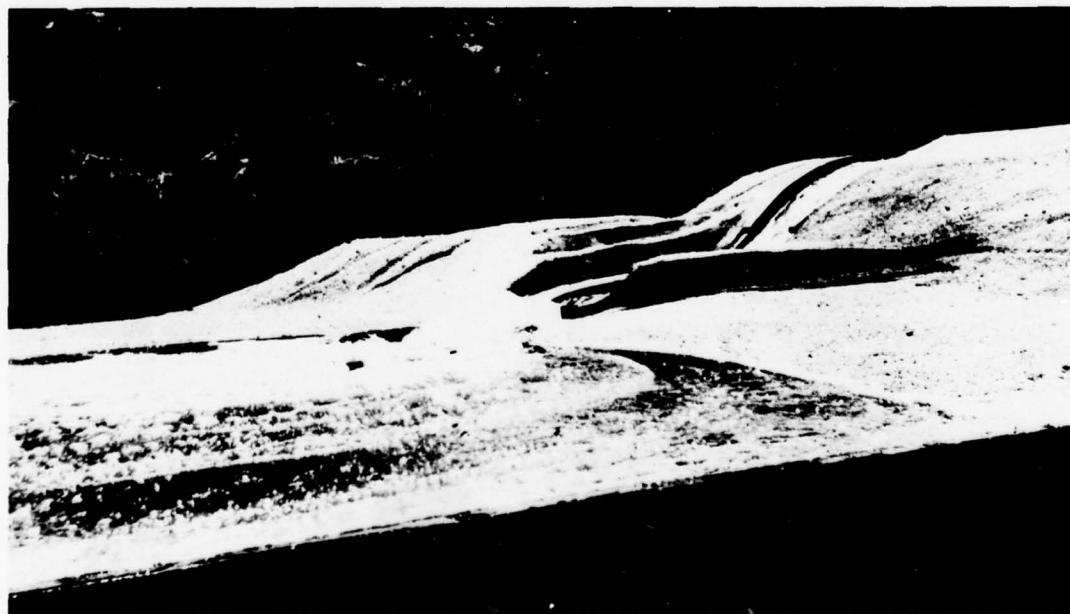


Photo 3. Final design, 1:48-scale model, general view of
spillway chute and bucket



a. Upstream view



b. General view

Photo 4. Final design flow conditions, 1:48-scale
model, discharge 54,000 cfs

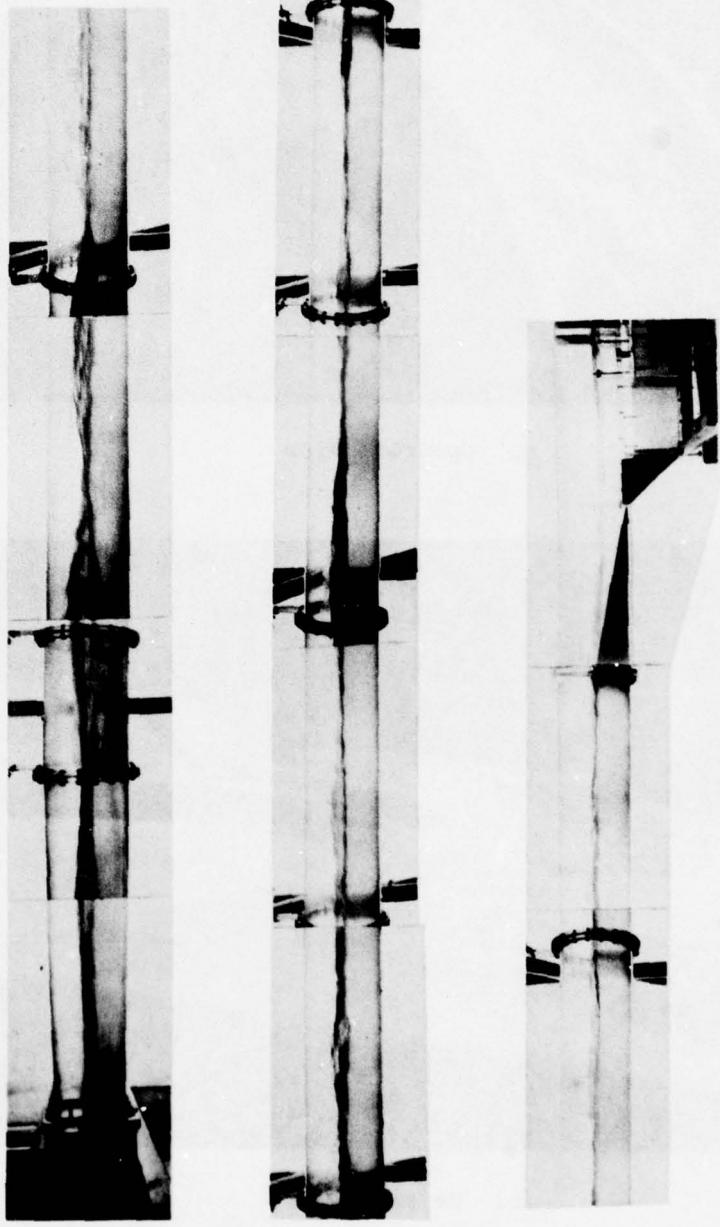
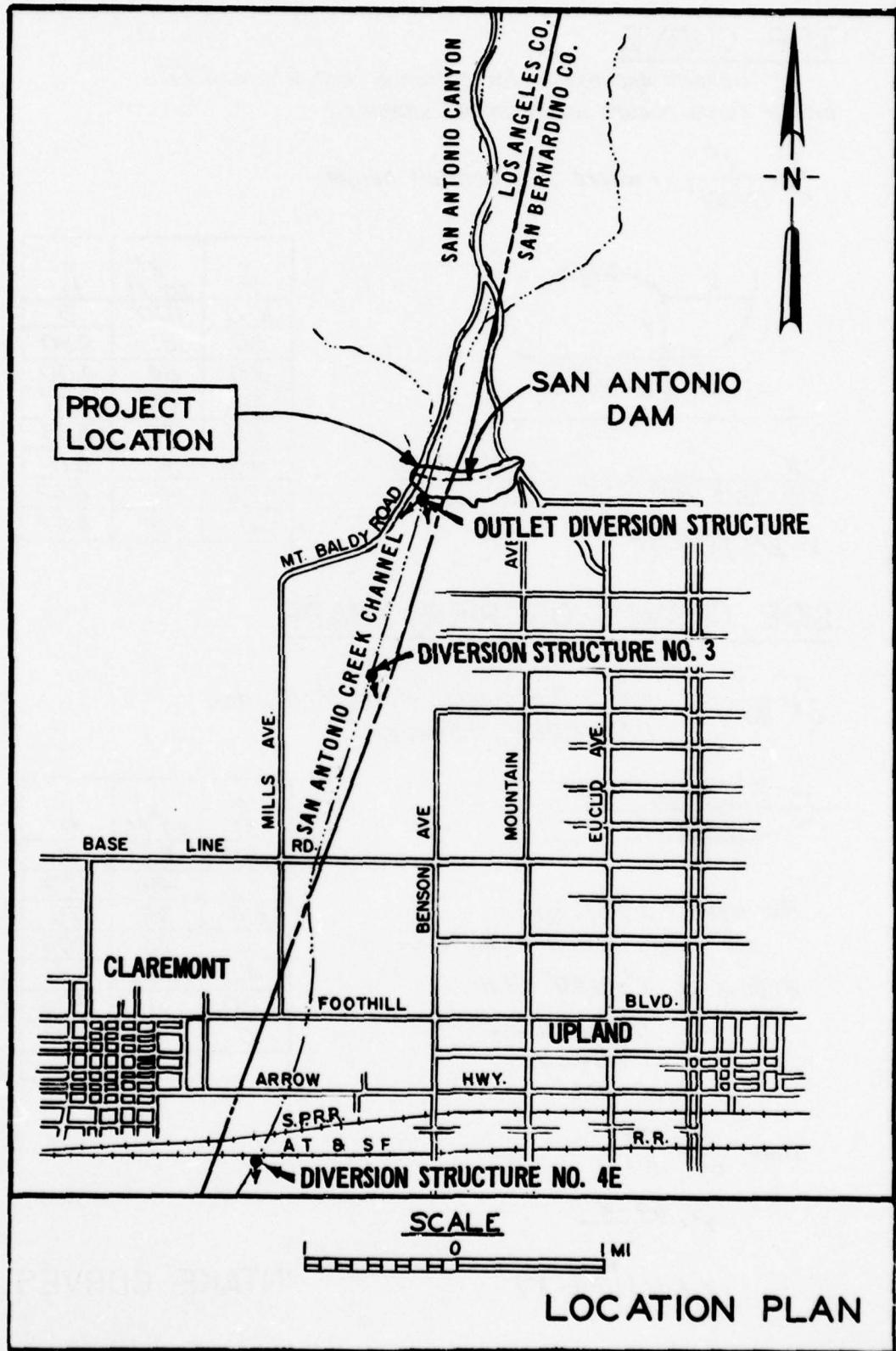


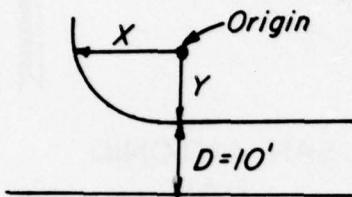
Photo 5. Flow conditions in outlet works, 1:20-scale model;
discharge 5,000 cfs and gate openings 6.0 ft



TOP CURVE

General expression for entrance roof when no bell-mouth curve occurs in the invert shape is:

$$\frac{X^2}{D^2} + \frac{Y^2}{(2/3D)^2} = 1 \text{ where } D \text{ is conduit height.}$$



$$\frac{X^2}{100} + \frac{Y^2}{(2/3 \cdot 10)^2} = 1, \text{ or } Y^2 = \frac{4(100-X^2)}{9}$$

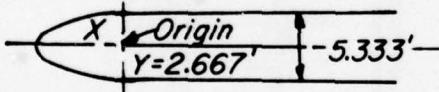
$$Y = 2/3 \sqrt{100-X^2}$$

X ft	X ² sq ft	Y ft
10.0	100	0
9.0	81	2.90
8.0	64	4.00
7.0	49	4.75
6.0	36	5.33
4.0	16	6.11
2.0	4	6.52
0	0	6.67

SIDE CURVES OR PIER SHAPE

$$\frac{X^2}{D^2} + \frac{Y^2}{(D/3)^2} = 1 \text{ where } D \text{ is conduit width, } 5'-8", \text{ and}$$

$$D/3 = 1.889', \text{ however,}$$



Pier width = 5.333', so
use an ellipse with Y = 2.666'---

$$\text{When } X=0, Y^2 = (D/3)^2 = 7.111\dots$$

$$D^2 = 9 \times 7.111\dots$$

$$= 64.00$$

$$\therefore D = 8.0'$$

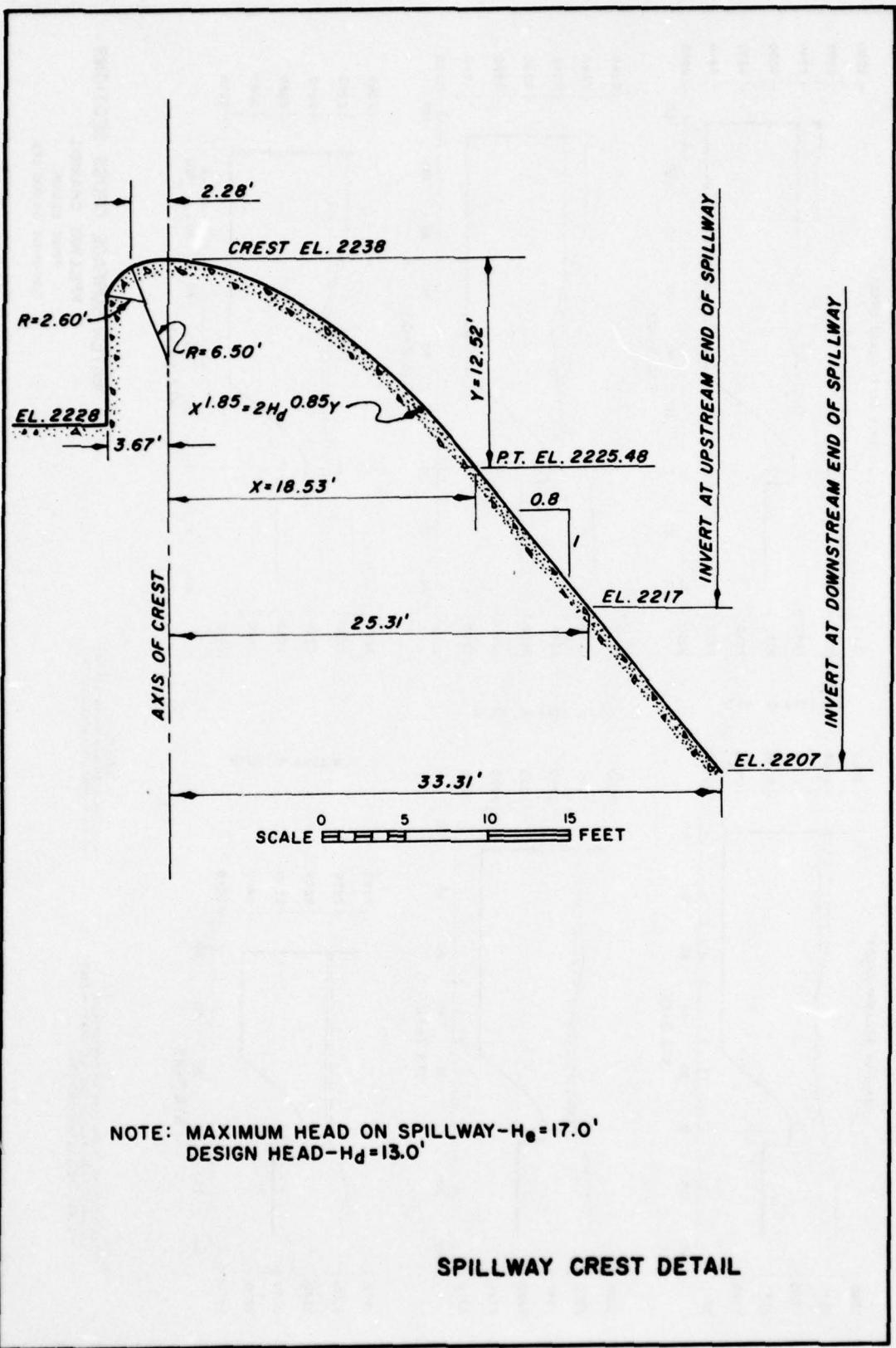
$$\text{Then } \frac{X^2}{64} + \frac{9Y^2}{64} = 1$$

$$Y^2 = \frac{64-X^2}{9}$$

$$Y = 1/3 \sqrt{64-X^2}$$

X ft	X ² sq ft	Y ft
8.0	64	0
7.0	49	1.29
6.0	36	1.76
5.0	25	2.08
4.0	16	2.31
2.0	4	2.58
0	0	2.67

INTAKE CURVES



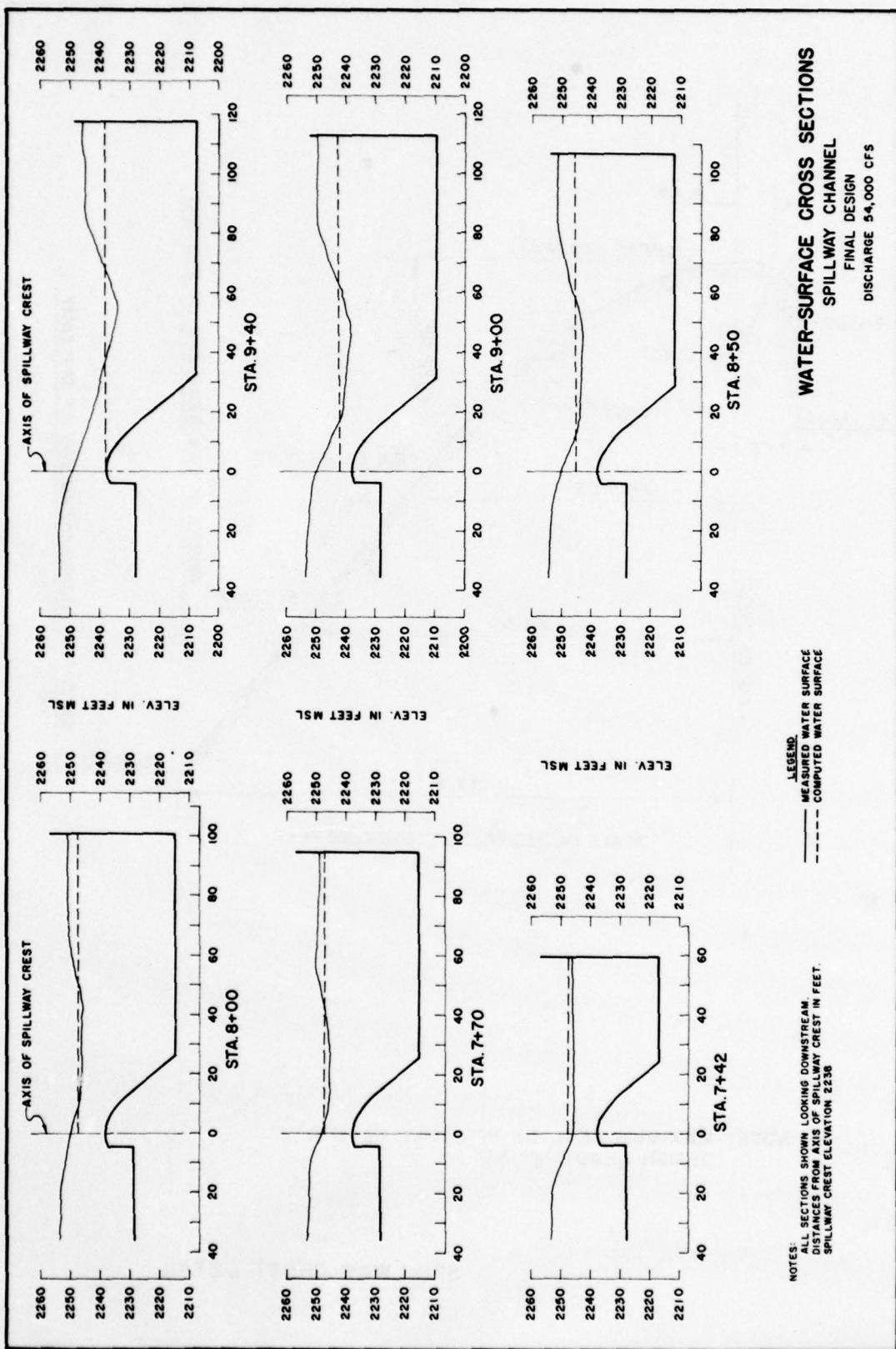
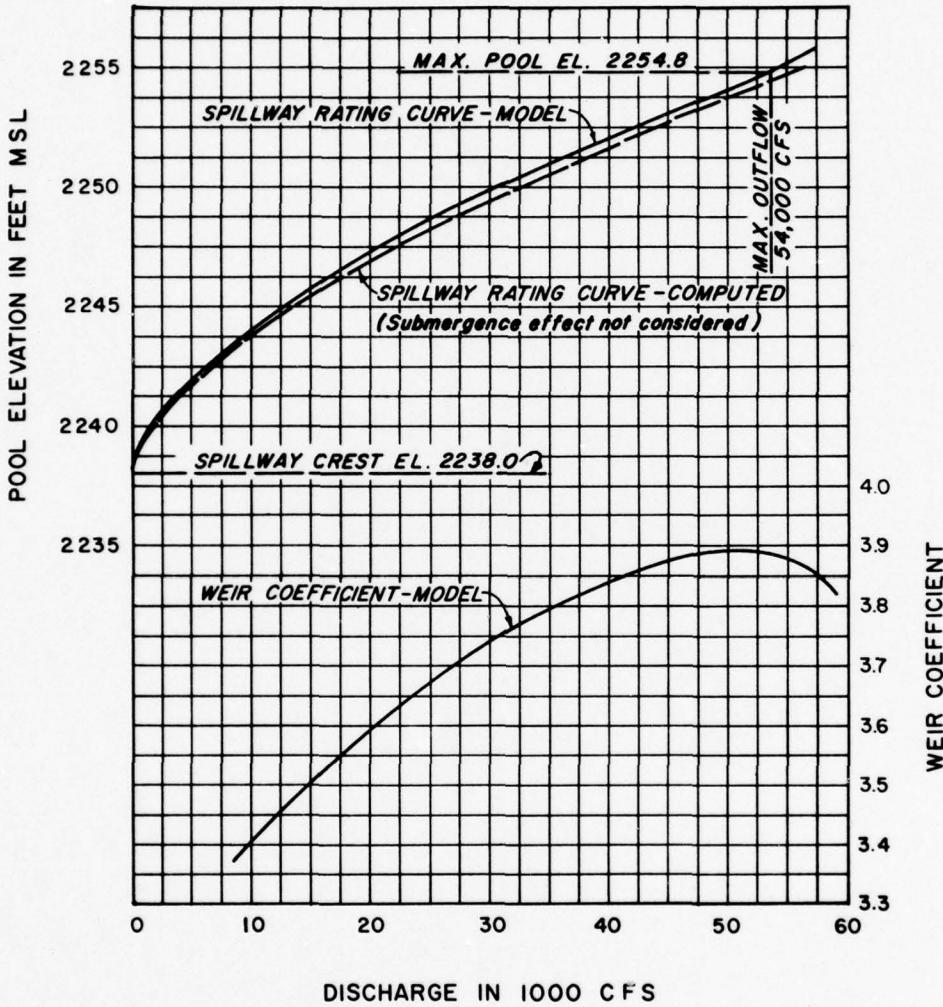
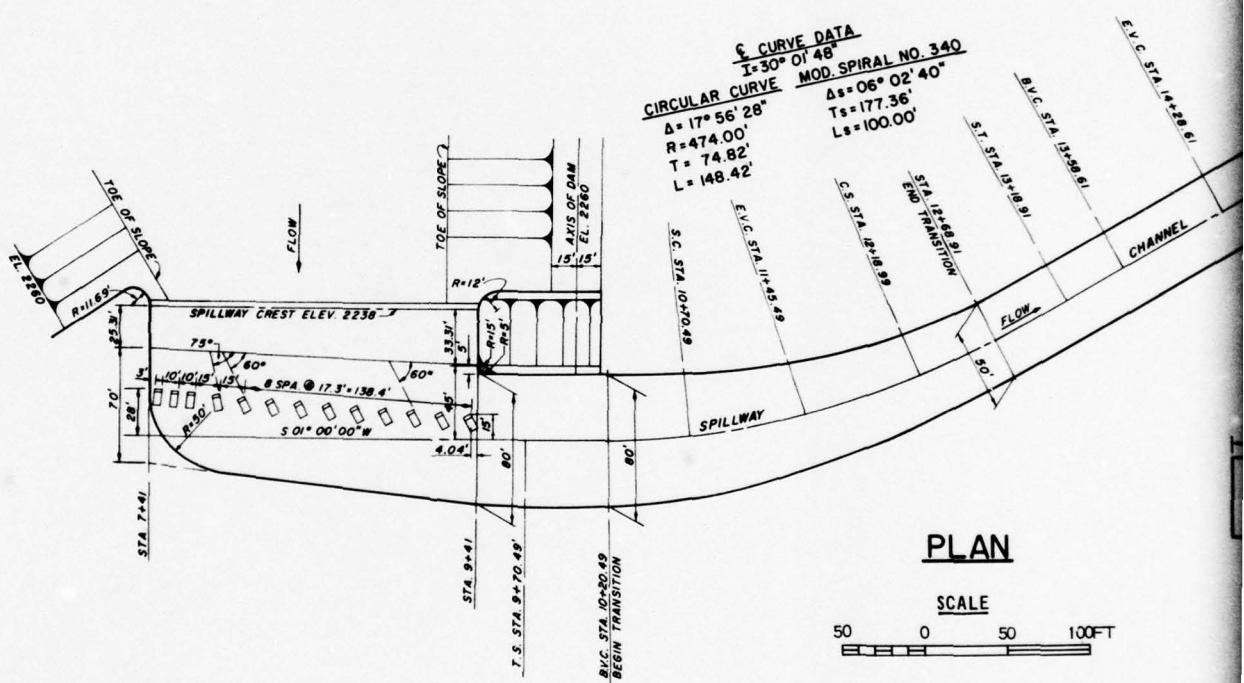


PLATE 4

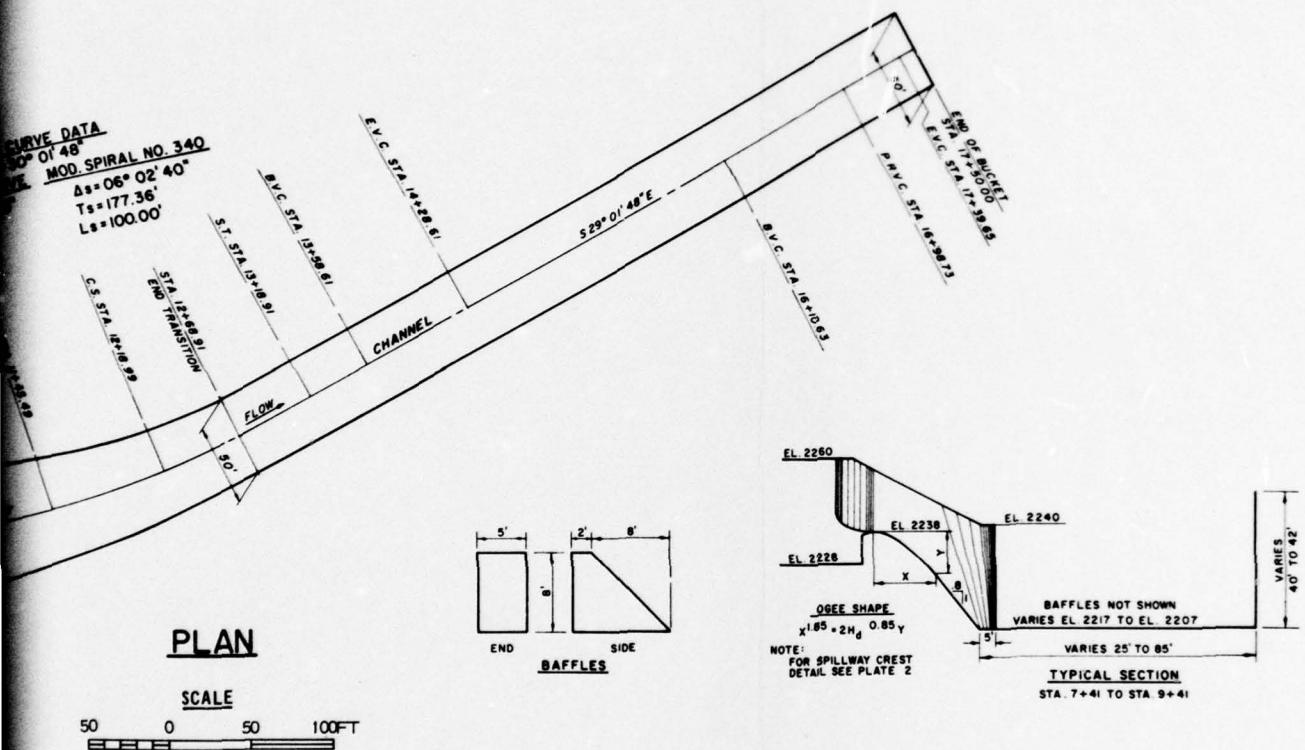


NOTE: MODEL COEFFICIENT "C" COMPUTED FROM
 FORMULA, $Q = CLH^{3/2}$
 L=200.0 FEET, LENGTH OF SPILLWAY CREST
 H=HEAD ON SPILLWAY CREST

SPILLWAY RATING CURVE

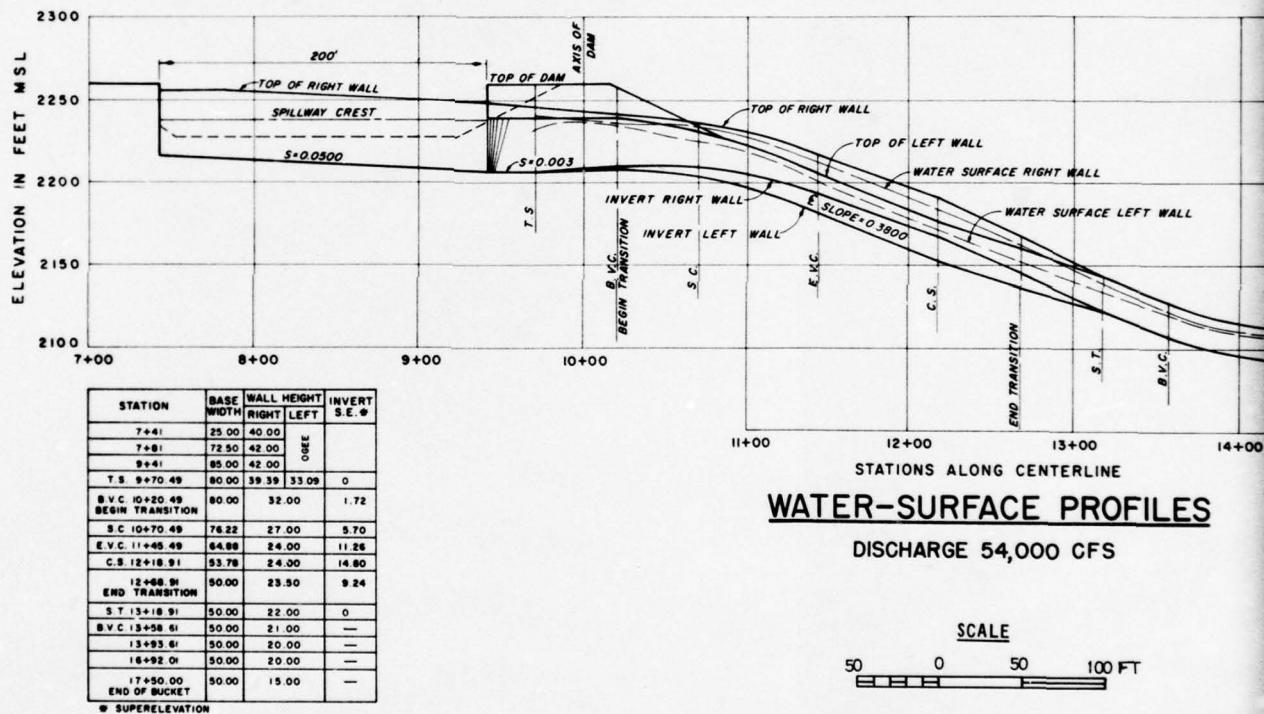


2



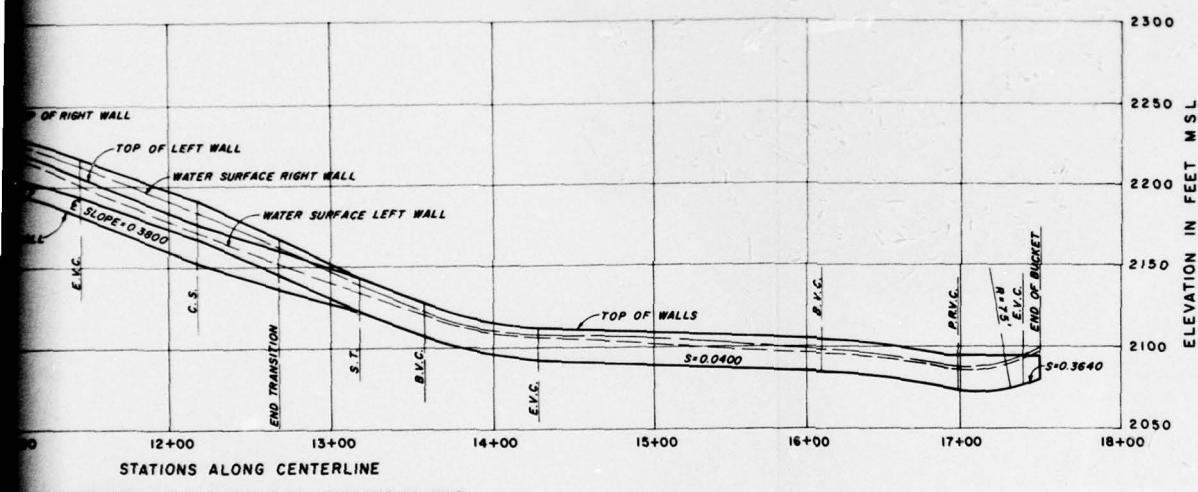
MODEL DETAILS FINAL DESIGN

PLATE 6

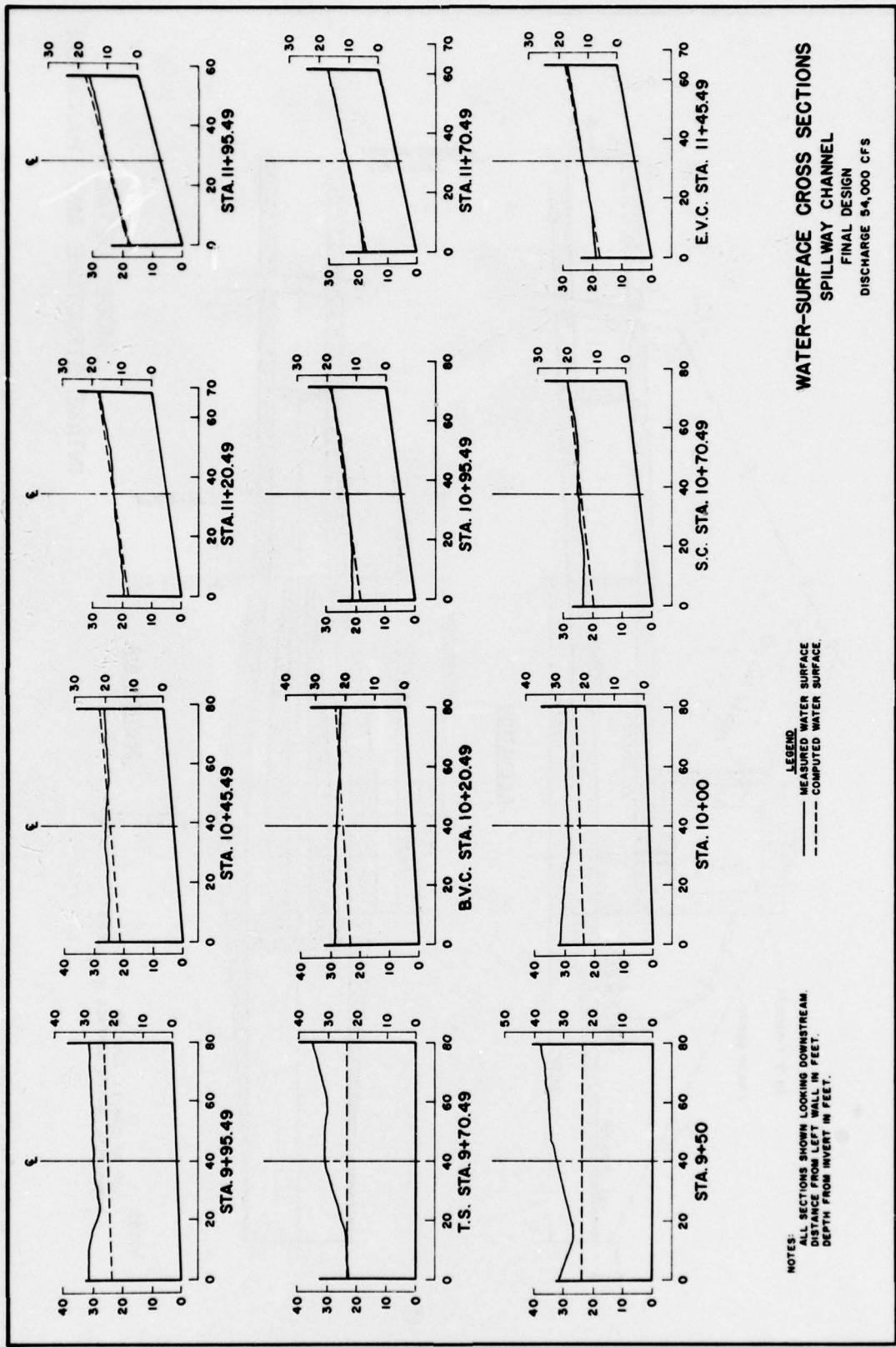


SEE ALSO PLATE 6

2



WATER-SURFACE PROFILES
FINAL DESIGN



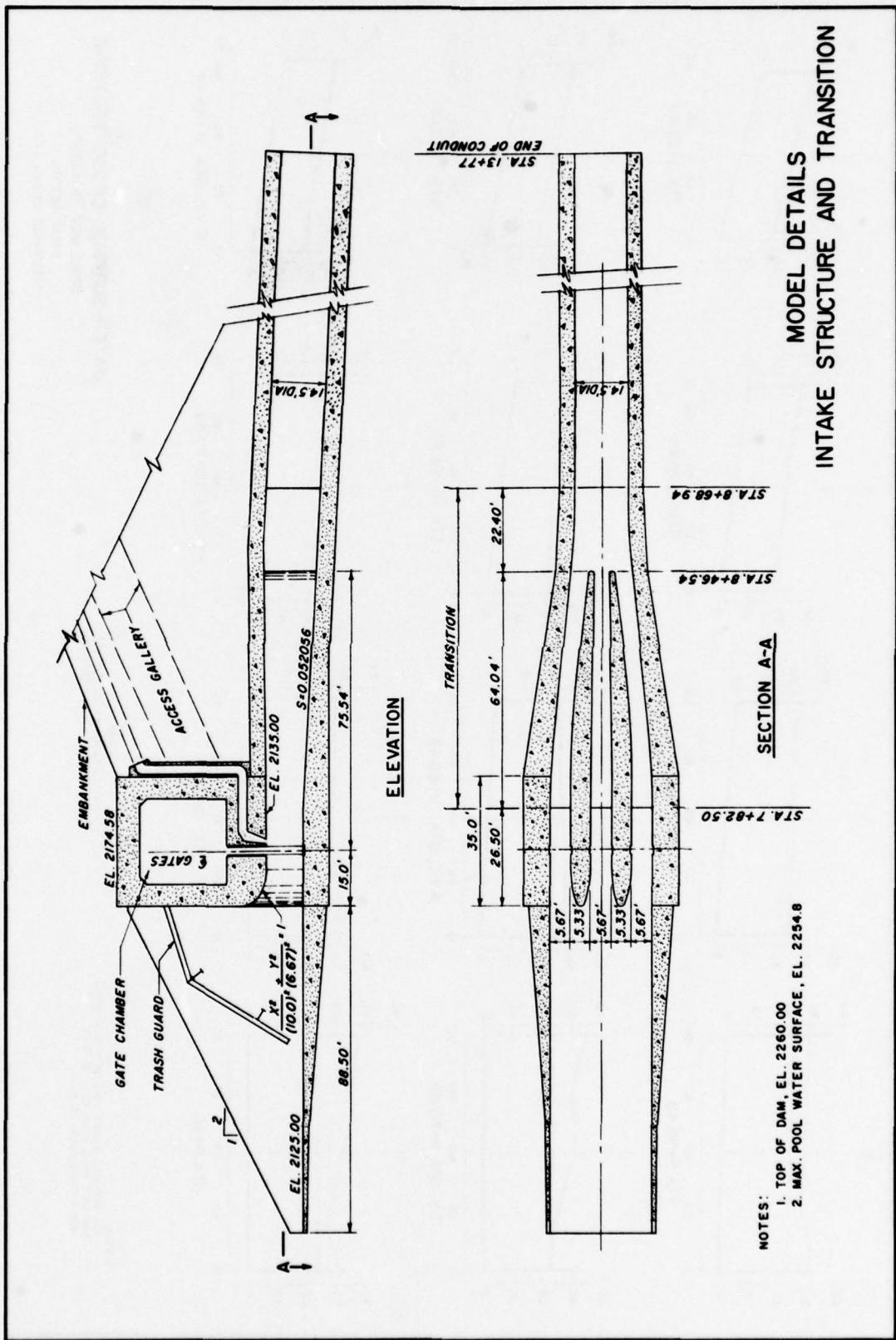
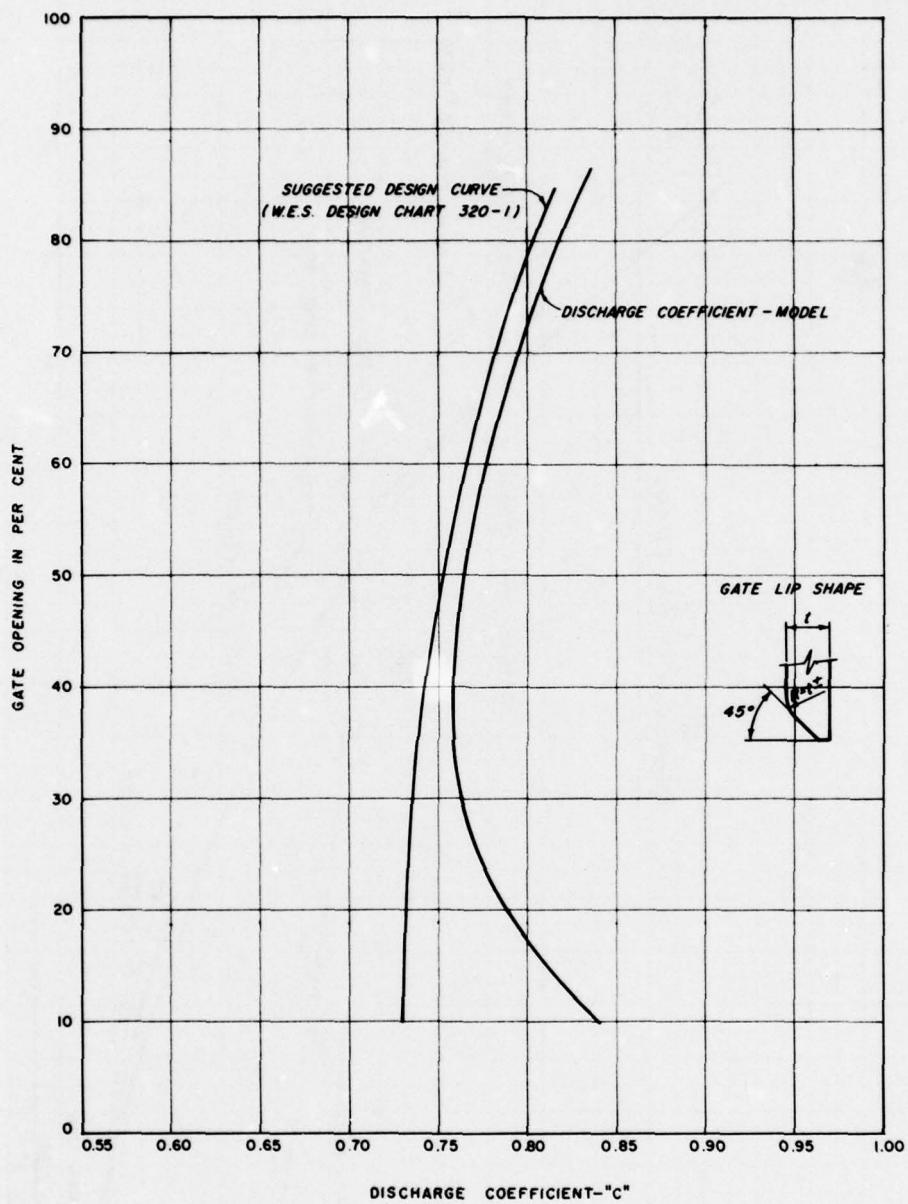


PLATE 9



NOTES:

1. THREE GATES WITH EQUAL OPENING.
2. WIDTH OF EACH GATE, 5'-8".
3. COEFFICIENT PLOTTED IS AVERAGE VALUE OF EACH GATE OPENING.
4. "C" COMPUTED FROM FORMULA $Q = CA \sqrt{2gH}$, WHERE H = DIFFERENCE BETWEEN POOL ELEVATION AND TOP OF OPENING.

CONTROL GATES
DISCHARGE COEFFICIENT
FOR PARTIAL GATE OPENING

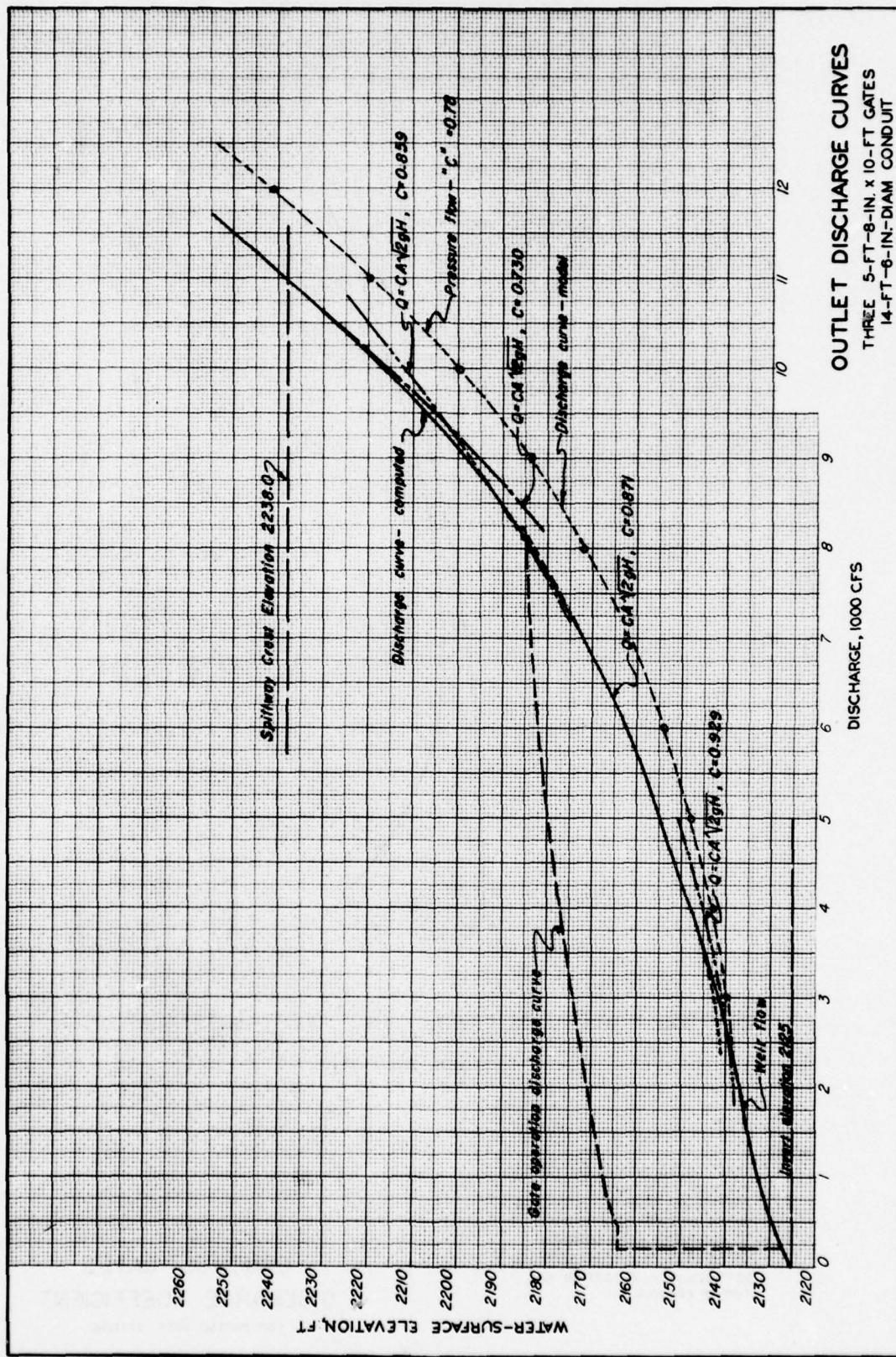
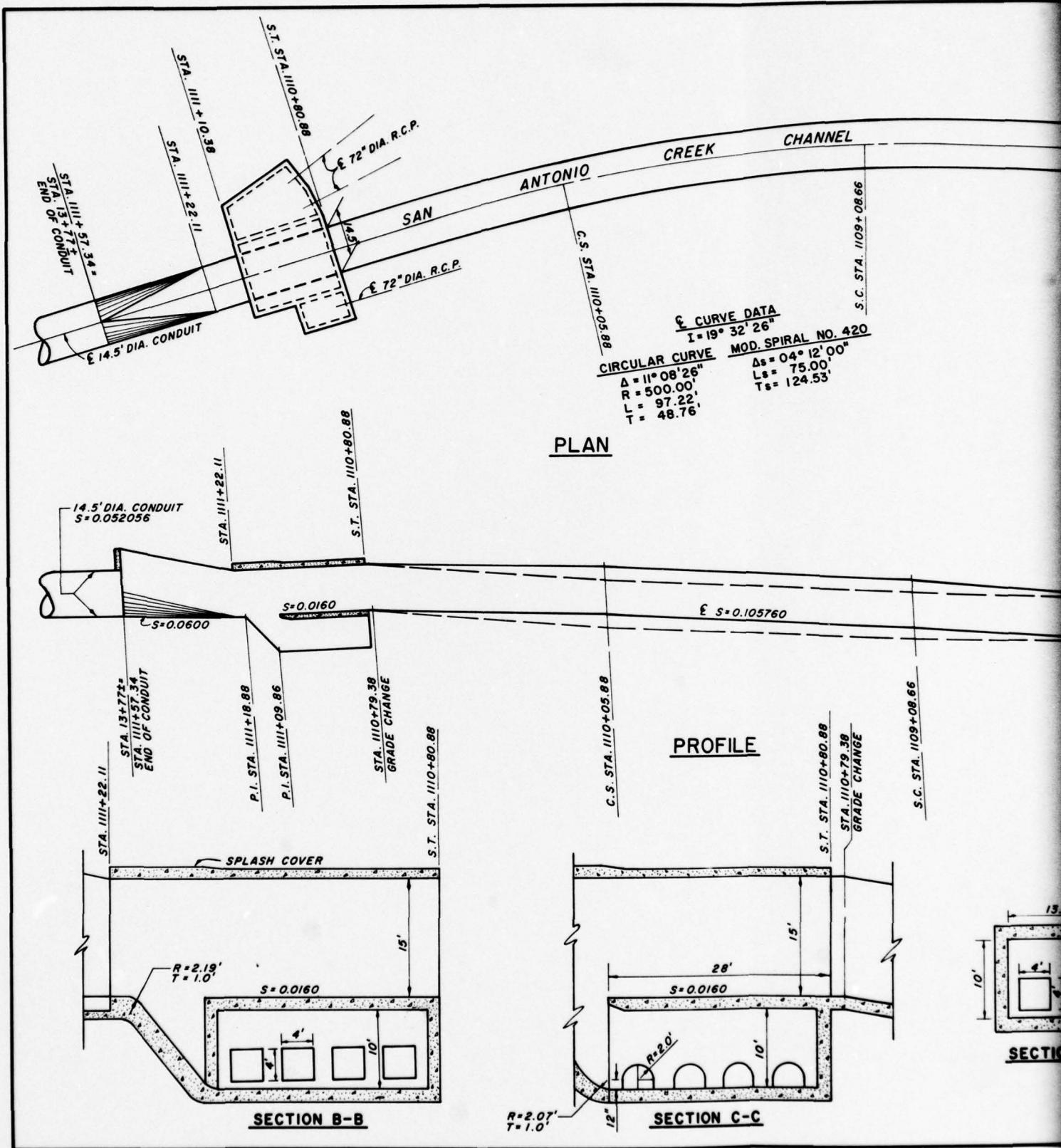
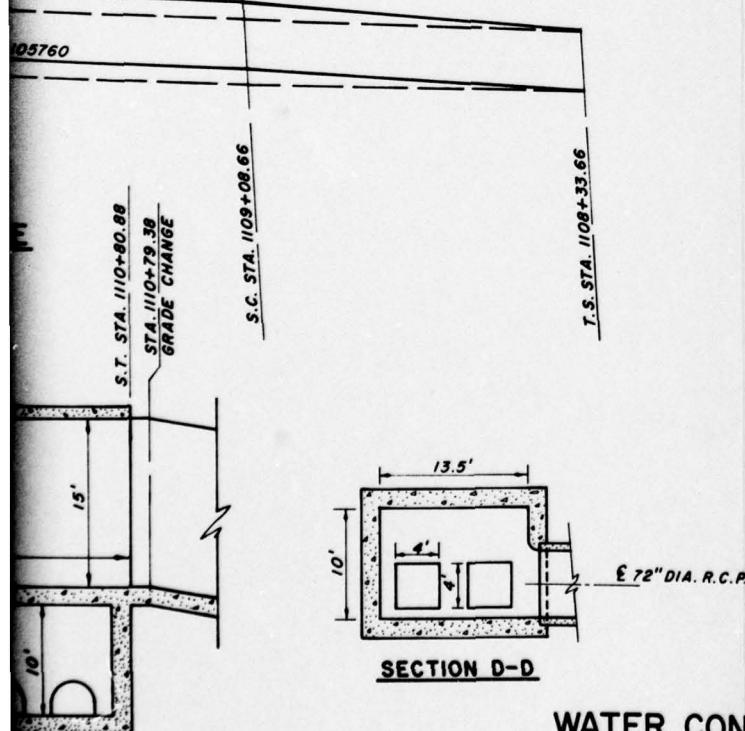
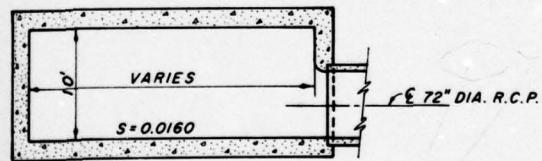
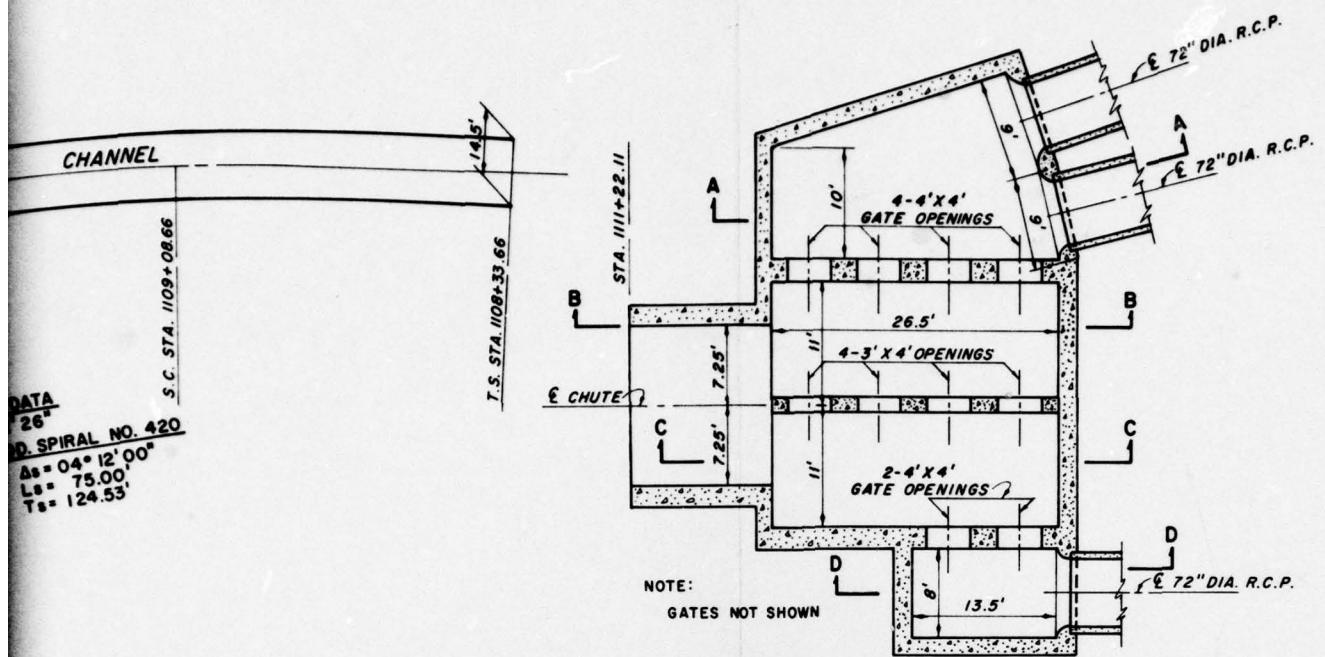


PLATE 11



2



WATER CONSERVATION DIVERSION STRUCTURE
PLAN, PROFILE, AND SECTIONS

APPENDIX A: SAN ANTONIO CREEK CHANNEL DIVERSION
STRUCTURES NO. 3 AND NO. 4-E

Description of Structures

1. Two model studies were made of two different spreading ground diversion structures: Diversion Structure No. 3, located at sta 1035+00 about 8,000 ft from San Antonio Dam, and Diversion Structure No. 4-E, 16,000 ft farther downstream at sta 875+00. The general plan and profile of each diversion structure are shown in Plate Al.

2. Diversion Structure No. 3 is designed to divert 300 cfs from the main San Antonio Creek channel by means of a slot opening in the channel invert through which water flows into a diversion channel under the main channel. The main channel is designed as a rectangular channel 20 ft wide and has a slope of 0.045882. The 6-ft-long slot in the invert covers the entire width of the channel. An ogee-shaped invert conveys the flow to a covered channel which converges from 20 to 5 ft in width. A slide gate is set in a gate well located adjacent to the main channel wall to control the flow. Downstream from the gate well is a covered box followed by a 5-ft-wide by 50-ft-long stilling basin. A 7-ft-high end sill is composed of flashboards. Connected to the stilling basin downstream is a rock-lined trapezoidal diversion channel. It was desired to make tests for discharges in the main channel ranging between 300 and 2,000 cfs with a corresponding range of velocities between 19 and 37 fps.

3. For Diversion Structure No. 4-E, the invert of the main channel beginning at sta 875+00 was depressed to form a low-water channel that would be capable of diverting 100 cfs into a diversion channel. The low-flow diversion channel converges from the width of the main channel at sta 875+00 to a 7-ft section at sta 873+90. Downstream from sta 873+90, the base width of the low-flow diversion channel continues to be 7 ft. From the drop inlet to the gate well the diversion channel is a covered section. Downstream from the gate well, the diversion channel is similar to Diversion Structure No. 3.

Purpose of Investigation

4. Model studies of the diversion structures were necessary because of the design problems encountered for which there were no mathematical solutions or precedents. The pertinent information to be determined was: (a) the shape and size of the diversion channel, (b) disturbances, if any, to the flow in the main channel resulting from the diversion works, (c) adequacy of the diversion structures to divert their required discharges during the high flows in the main channel, and (d) the amount of pressure in the gate well and on the gate when it is closed.

Description of Models

5. Diversion Structure No. 3 and Diversion Structure No. 4-E were constructed to undistorted-scale ratios of 1:15 and 1:25, respectively. The two models reproduced a portion of the San Antonio Creek channel, the curved diversion channel located beneath the invert slab, the low-flow diversion channel, the gates, stilling basins, and rock-lined channels. The slide gates were located just outside the left wall in a rectangular gate well. The flows from the diversion structures were diverted into 5-ft-wide concrete stilling basins. The stilling basins are designed for a maximum velocity of 40 fps. The rock-lined channels downstream from the stilling basins have a slope of 0.001, a base width of 10 ft, and 1V-on-2H side slopes.

Description of Tests

6. No attempt was made to obtain quantitative data during the tests; therefore model tests were accomplished by visual observation and the results were recorded by photographs.

Diversion Structure No. 4-E

7. The diversion structure was designed to divert 100 cfs from the main San Antonio Creek channel by means of a low-water channel, a

drop inlet, a gate well, and a covered section. The recommended design provided for a 30-ft-long stilling basin, controlled by a 1.0-ft-high end sill. With flows of 100, 125, 500, 2,000, 5,000, and 8,600 cfs, observations were made to determine if the proposed diversion structure caused any disturbances to the flow in San Antonio Creek channel. The proposed design of the structure proved to be adequate to fully divert the necessary discharge from the main channel. Testing was begun by allowing 100 cfs to flow in San Antonio Creek channel. With this discharge, all flow was diverted toward the inlet to the diversion channel. Then it was to be determined if 100 cfs could be diverted with flows of 125, 500, 2,000, 5,000, and 8,600 cfs in the main channel. Model investigations showed flow conditions in the main channel and in the immediate area over the low-water channel to be generally satisfactory. Photos A1-A16 illustrate the flow conditions for the various discharges. (The "mirror-image" layout of the model relative to the prototype was necessitated by space restrictions at the model site.)

Diversion Structure No. 3

8. The main problems of concern were the flow distribution in the curved portion of the diversion channel under the main channel invert and the influence of the curved approach upon the discharge through the gate well. The investigation showed that for most of the discharges, flow conditions in the curved sections and in the section downstream from the gate well were generally satisfactory. The tests were conducted by establishing a sequence of discharges and setting the gate opening to divert a certain discharge. The slot inlet intercepted a maximum discharge of 350 cfs before any flow would continue down the main channel. For flows greater than 350 cfs, with the gate opened and closed, waves were set up in the channel by the slot inlet in the invert that created a spray which covered a wide area. The spray ceased to exist when the discharge in the main channel was greater than 1,000 cfs. A gage installed on the cover of the gate well indicated a maximum pressure head of 15 ft. Visual results at various discharges are shown in Photos A17-A31.

9. A 50-ft-long stilling basin with a 3-ft-high end sill was

recommended for this diversion structure. A 25-ft-long grouted-stone channel was required downstream from the end sill. Without the grouted-stone apron, scour below the end sill was excessive.

Prototype Performance

10. San Antonio Creek channel extends downstream for about 16 miles from San Antonio Dam (at the mouth of San Antonio Canyon) to Prado Reservoir (on the Santa Ana River). The drainage area tributary to the project is estimated at 93 square miles. The design capacities range from 8,000 cfs, the controlled outflow from San Antonio Dam, to 29,000 cfs at the downstream end. The design discharge with all gates fully open and reservoir water surface at el 2,238 is 11,000 cfs.

11. The first major flood after completion of the project (1958) occurred in December 1966. The peak flow was estimated at 4,000 cfs. The flood, which was about one half the magnitude of the maximum controlled discharge, caused no damage to the project. The prototype performance of the diversion structures was considered satisfactory.

12. A severe flood occurred on 25 January 1969. Peak discharge was 8,400 cfs and the movement of debris was astounding. The diversion structures sustained some damages due to the excessive amount of debris carried by the flow. Noticeable vibration and loud noise occurred in Diversion Structure No. 3, due to the debris trapped in the gate chamber that bounced violently against the gate and concrete walls. This action resulted in impact and abrasion damage to the concrete structure. The lid of the gate well was blown off and the gate was damaged beyond repair. The gate chambers were filled with silt, sand, gravel, and rock. The sides of the chambers were rough and pitted. This flood provided the opportunity to check the amount of debris accumulated in the diversion chambers which could not be done in the model.

13. The debris load coupled with the high-velocity flow was a contributing factor to the eroded edges and corners of the drop inlets. In places, the erosion was deep with aggregate but no reinforcing steel was exposed.

14. Due to the relatively mild, although extensive, damage to the downstream edges of the drop inlets, steel plates were installed along the full width of the inlet to prevent abrasion damage by debris and rock coming through the dam. It was recommended that trashrack bars be installed at the entrance to the inlet to prevent large debris and rock from entering the diversion structure.

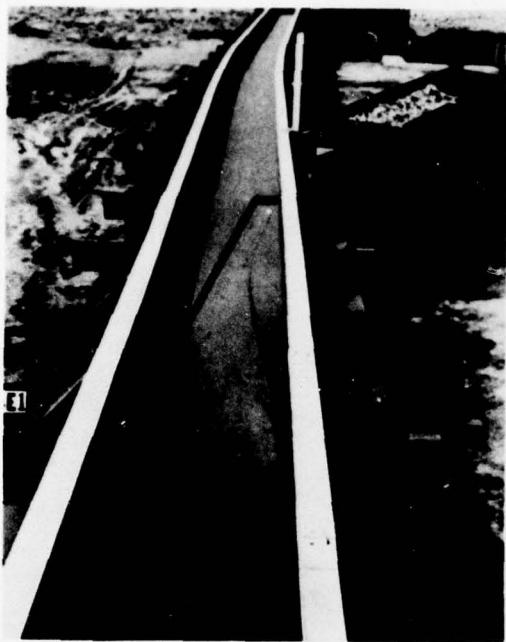


Photo A1. Looking downstream at diversion slot



Photo A2. Close-up of diversion channel

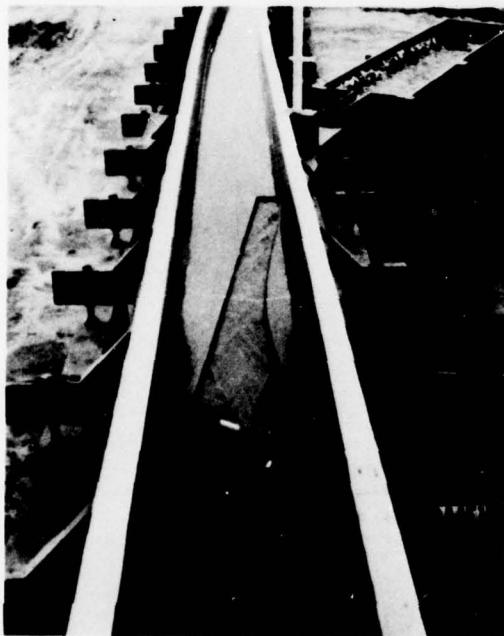


Photo A3. Looking downstream with diversion gate open,
 $Q = 100 \text{ cfs}$

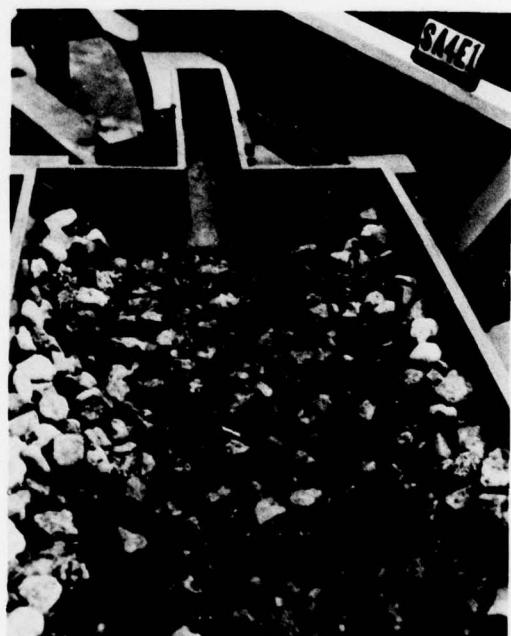


Photo A4. Looking upstream with diversion gate open at flow entering diversion channel,
 $Q = 100 \text{ cfs}$

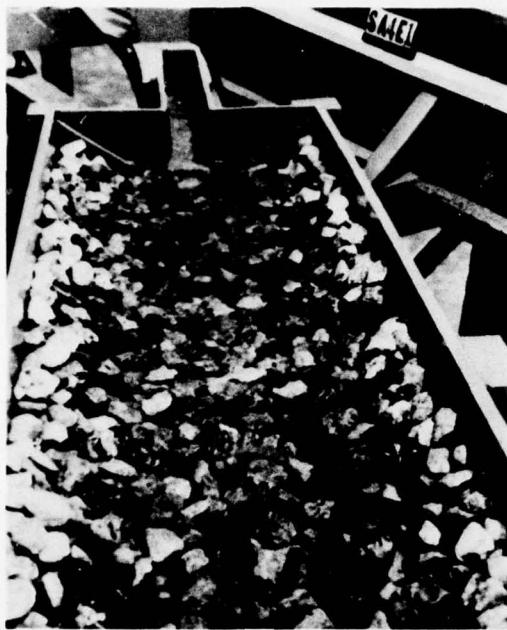


Photo A5. Looking upstream at flow entering diversion channel with gate open, $Q = 125$ cfs



Photo A6. Looking downstream with diversion gate open, $Q = 125$ cfs

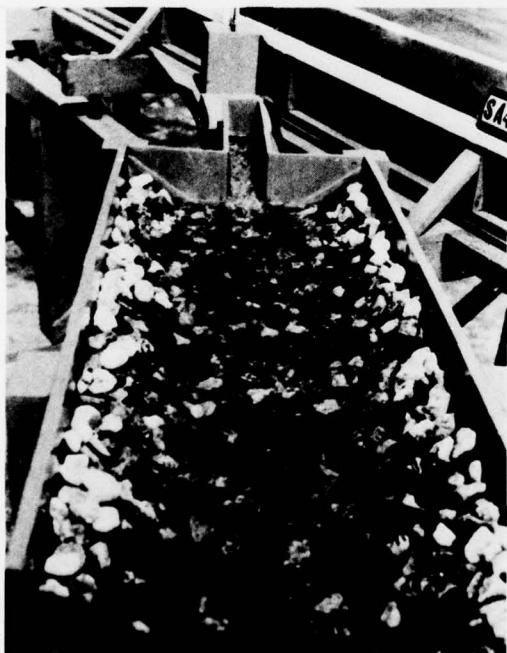


Photo A7. Looking upstream at flow entering diversion channel with diversion gate partially open to pass 100 cfs. $Q = 500$ cfs in main channel



Photo A8. Looking downstream at flow past slot, $Q = 500$ cfs. Diversion gate partially open to pass 100 cfs

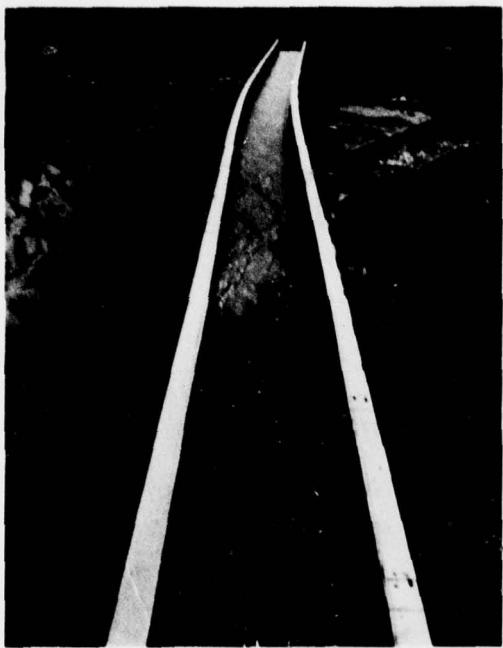


Photo A9. Looking downstream at flow past slot with diversion gate open, $Q = 500$ cfs



Photo A10. Looking downstream at flow past slot with diversion gate open, $Q = 2,000$ cfs



Photo A11. Looking upstream at flow entering diversion channel with diversion gate fully open, $Q = 260$ cfs. $Q = 2,000$ cfs in main channel



Photo A12. Looking upstream at flow entering diversion channel with diversion gate partially open to pass 100 cfs. $Q = 5,000$ cfs in main channel

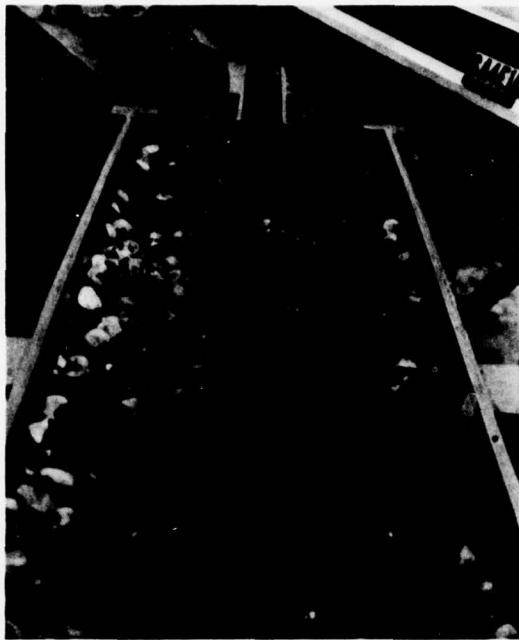


Photo Al3. Looking upstream at flow entering diversion channel with diversion gate open, $Q = 300$ cfs. $Q = 5,000$ cfs in main channel



Photo Al4. Looking downstream at flow slot with diversion gate open, $Q = 5,000$ cfs

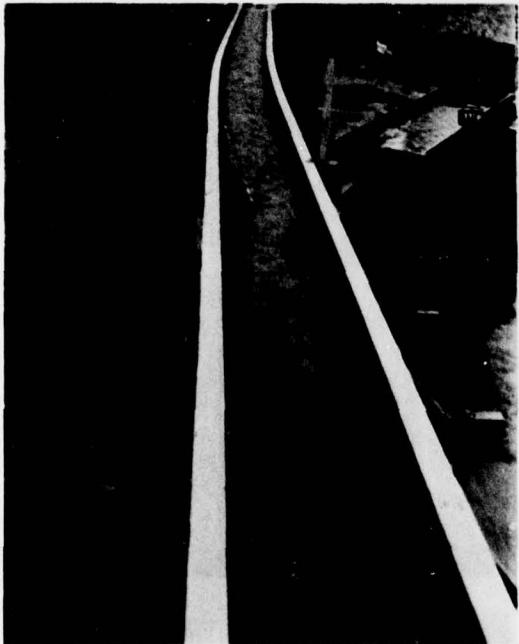


Photo Al5. Looking downstream at flow past slot with diversion gate open, $Q = 8,600$ cfs



Photo 16. Looking upstream at flow entering diversion channel with diversion gate open, $Q = 350$ cfs. $Q = 8,600$ cfs in main channel

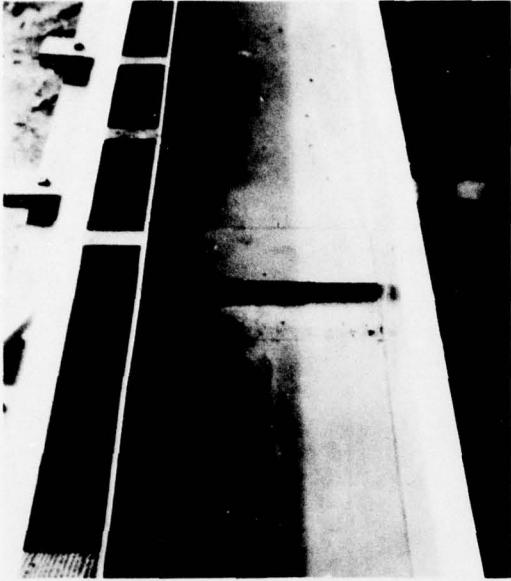


Photo A17. Looking downstream at entrance to diversion structure



Photo A18. Looking downstream at entrance to diversion structure with 300 cfs in main channel with diversion gate closed. A 6-ft-high splash occurred at the center of the channel and the entrance to the diversion structure

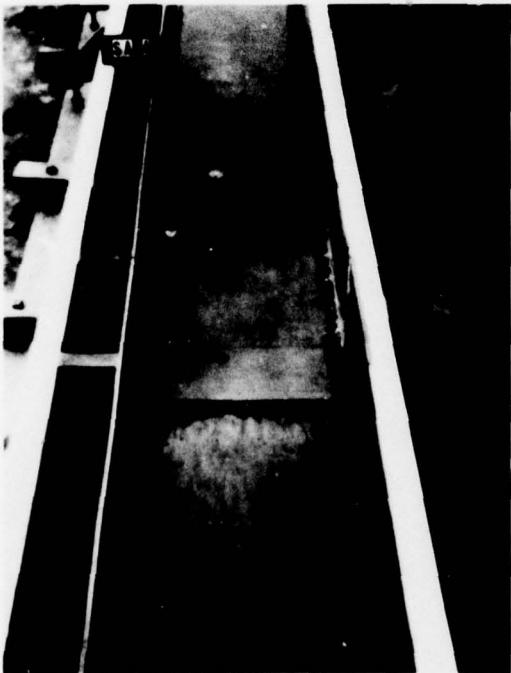


Photo A19. Looking downstream at 300 cfs passing through entrance to diversion structure with gate fully open

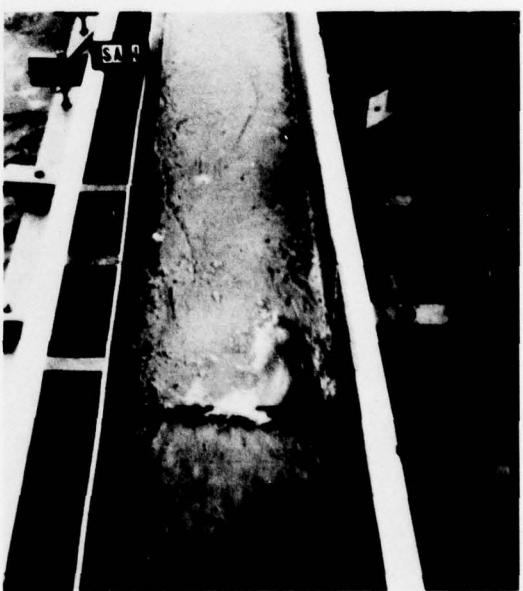


Photo A20. Looking downstream. 400 cfs in main channel, with 350 cfs flowing into the diversion structure with gate fully open

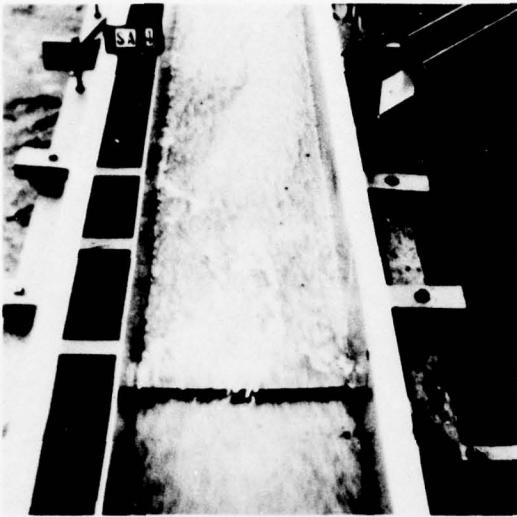


Photo A21. Looking downstream. 500 cfs in main channel, with 375 cfs flowing into the diversion structure with gate fully open

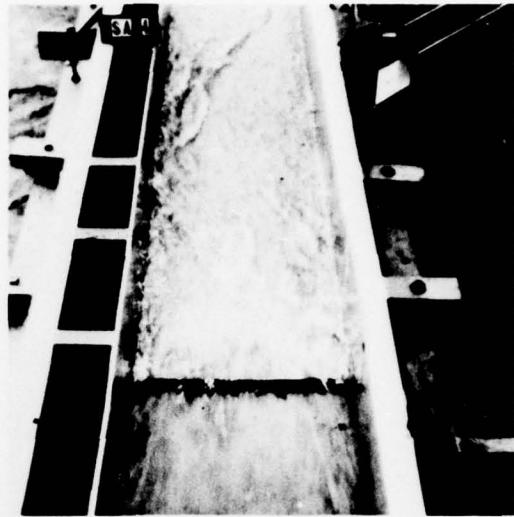


Photo A22. Looking downstream. 600 cfs in main channel, with 400 cfs flowing into the diversion structure with gate fully open. A heavy spray 15 ft high occurred at the entrance of the diversion structure with even distribution across channel

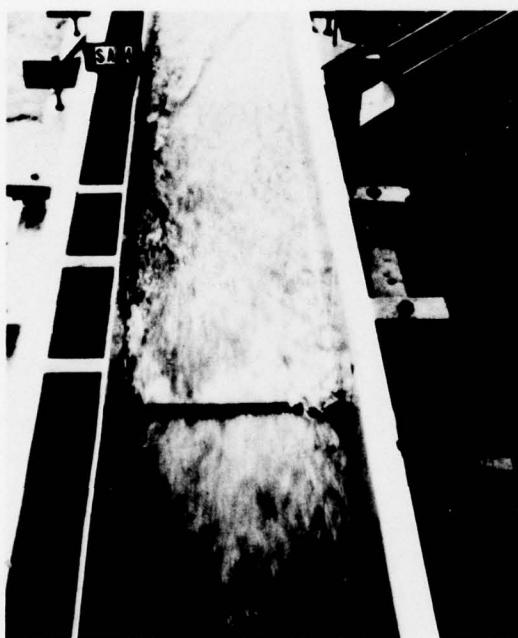


Photo A23. Looking downstream. 700 cfs in main channel, with 425 cfs flowing into the diversion structure with gate fully open. Balance passing down main channel. A heavy spray 15 ft high occurred at the entrance of diversion structure, evenly distributed across channel

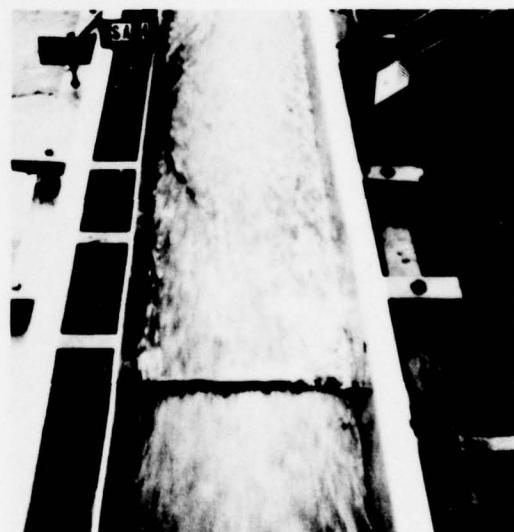


Photo A24. Looking downstream. 800 cfs in main channel, with 450 cfs flowing into the diversion structure with gate fully open. Heavy spray 15 ft high at right wall

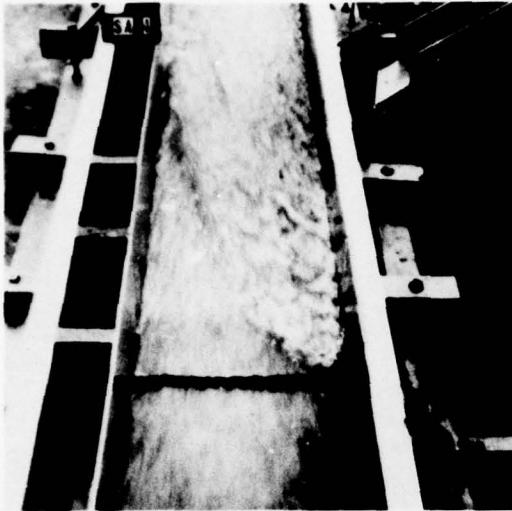


Photo A25. Looking downstream. 900 cfs in main channel, with 450 cfs flowing into the diversion structure with gate fully open. A disturbance occurred at right wall over entrance, creating cross waves downstream toward left wall

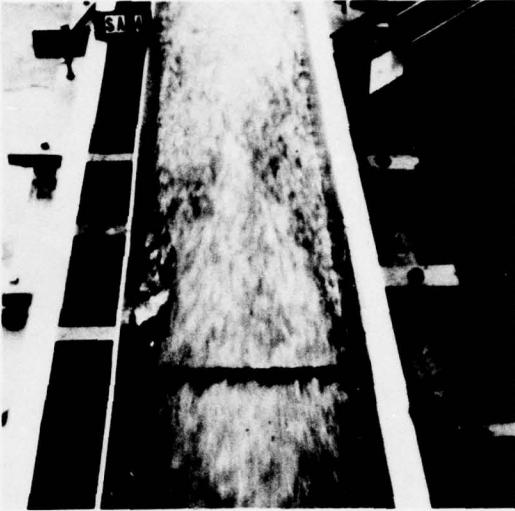


Photo A26. Looking downstream. 1,100 cfs in main channel, with 300 cfs flowing into the diversion structure controlled by diversion gate. A 3-ft-high wave occurred along left wall downstream of entrance

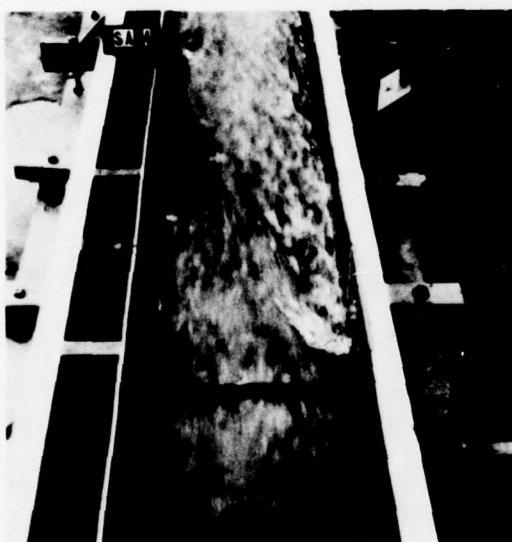


Photo A27. Looking downstream. 1,100 cfs in main channel with 300 cfs flowing into the diversion structure

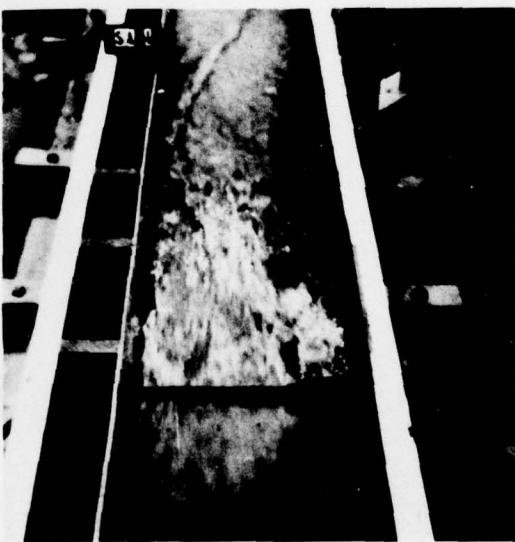


Photo A28. Looking downstream. 700 cfs in main channel, 400 cfs flowing into the diversion structure. A spray of 15 ft high occurred at entrance of diversion structure and formed a cross wave downstream from right wall toward left wall

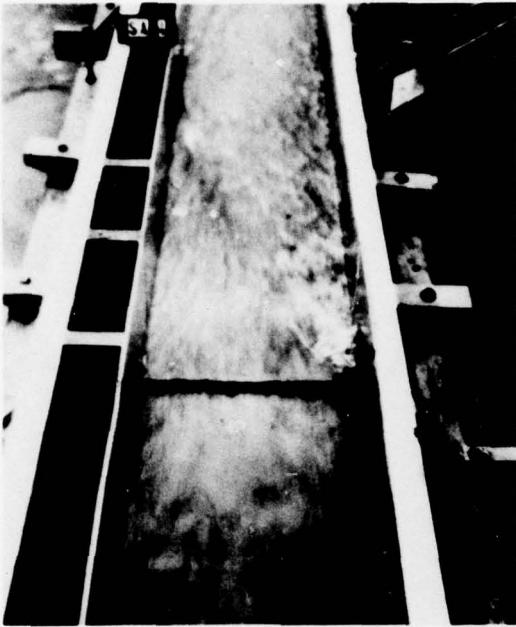


Photo A29. Looking downstream.
900 cfs in main channel, 400 cfs
flowing into the diversion struc-
ture. Spray occurred at right
wall of entrance to diversion
structure

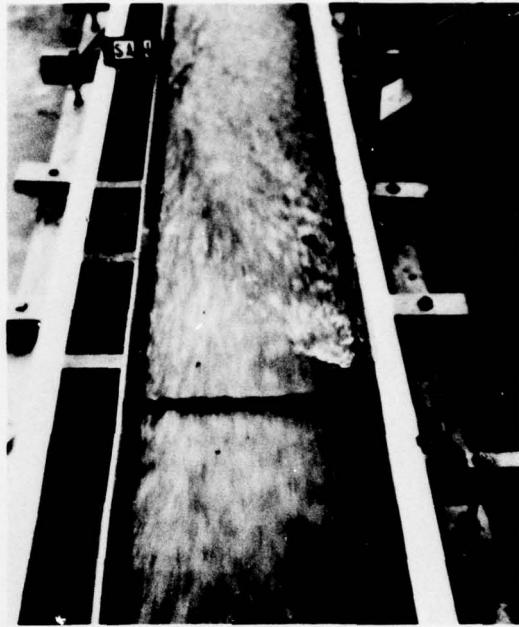


Photo A30. Looking downstream.
1,100 cfs in main channel, 400 cfs
flowing into the diversion
structure

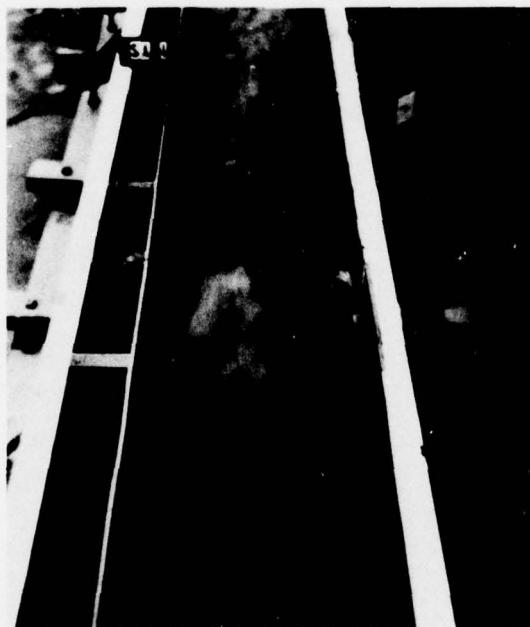
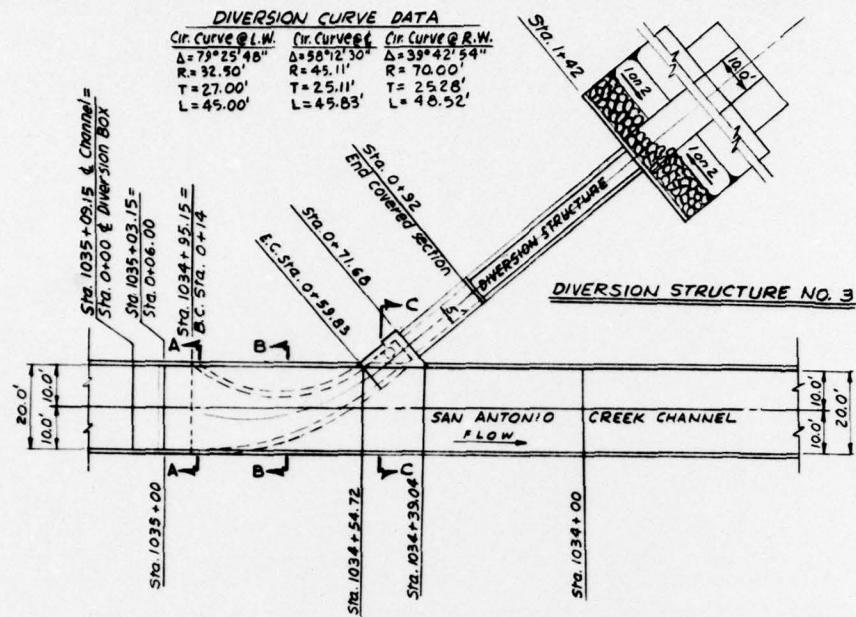


Photo A31. Looking downstream.
2,000 cfs in main channel, 400 cfs
flowing into the diversion
structure

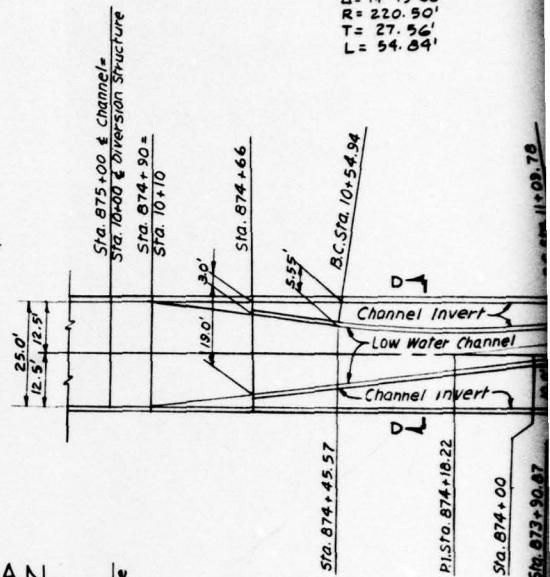
DIVERSION CURVE DATA

Cir. Curve @ L.W.	Cir. Curve @ E.	Cir. Curve @ R.W.
$\Delta = 79^{\circ} 25' 48''$	$\Delta = 58^{\circ} 12' 30''$	$\Delta = 39^{\circ} 42' 54''$
$R = 32.50'$	$R = 45.11'$	$R = 70.00'$
$T = 27.00'$	$T = 25.11'$	$T = 25.28'$
$L = 45.00'$	$L = 45.83'$	$L = 48.52'$

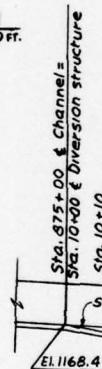
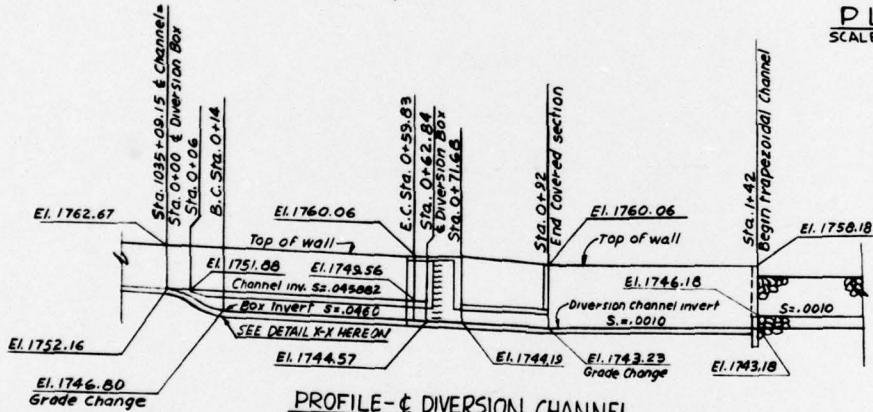


WALL CURVE DATA

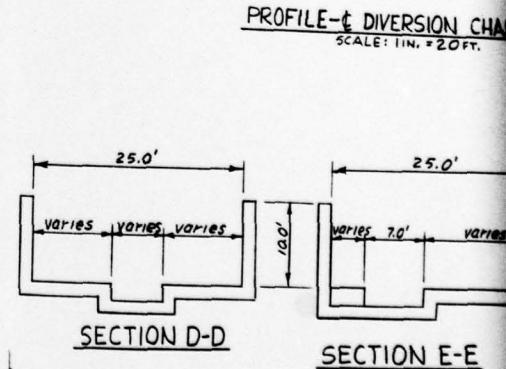
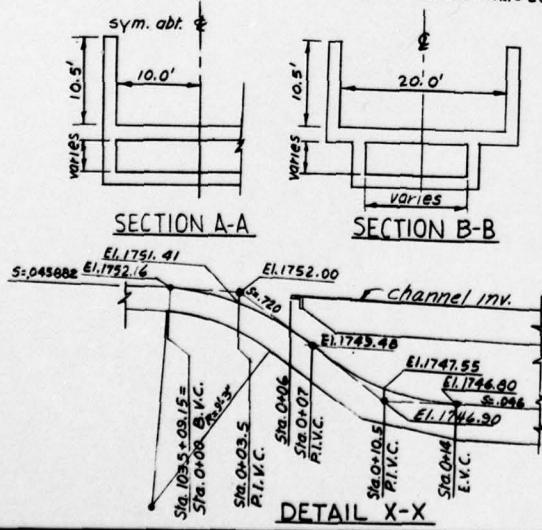
$\Delta = 14^{\circ} 15' 00''$	$R = 220.50'$
$T = 27.56'$	$L = 54.84'$



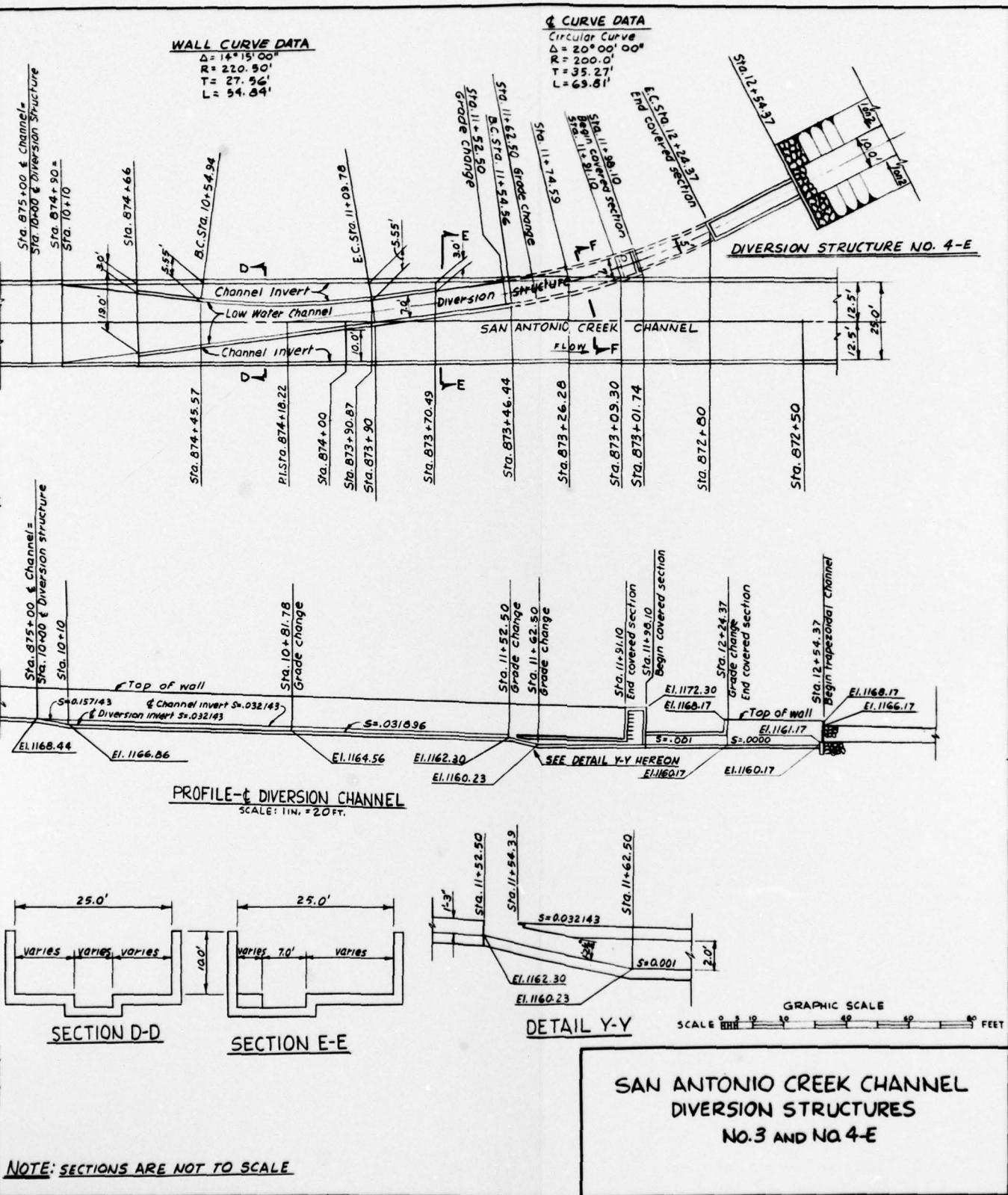
PLAN
SCALE: 1IN=20FT.



PROFILE - DIVERSION CHANNEL
SCALE: 1IN=20FT.



NOTE: SECTIONS ARE NOT TO SCALE



NOTE: SECTIONS ARE NOT TO SCALE

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Los Angeles District.

Side-channel spillway and outlet works for San Antonio Dam; hydraulic model investigation / by Dave A. Barela. Vicksburg, Miss. : U. S. Waterways Experiment Station, Springfield, Va. : available from National Technical Information Service, 1978.

vii, 15, 32 p., 9 leaves of plates : ill. ; 27 cm. (Report - U. S. Army Engineer District, Los Angeles ; 2-106)

1. Hydraulic models. 2. Outlet works. 3. San Antonio Dam.
4. Side channel spillways. I. Barela, Dave A. II. Series:
United States. Army. Corps of Engineers. Los Angeles District.
Report ; 2-106.
TC159.L6 no.2-106